# NAVAL POSTGRADUATE SCHOOL

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# THESIS

**THE EXTENSION OF WIRELESS MESH NETWORKS VIA VERTICAL TAKEOFF AND LANDING UNMANNED AERIAL VEHICLES**

by

John Paul Richerson

December 2007

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The evolution of integrated circuits, wireless communications, and data networking makes wireless networks practical for military and law enforcement applications. The objective of this thesis is to test and to evaluate network performance and suitability of an 802.11 wireless access point enabled vertical take off and land (VTOL) unmanned aerial vehicle (UAV) functioning as an airborne sensor and communications relay platform. Also, by identifying the production process of a COTS Remote Controlled Helicopter equipped with a wireless access point, a system, comprised of discrete technologies and production steps can be defined to gain insight into defeating an Aerial Improvised Explosive Device (AIED). Understanding the true capabilities of a small VTOL UAV, its applicability to a wireless network, and the production system associated with the manufacture of an AIED will allow proper planning, application and utilization in support of security and Force Protection missions and scenarios.

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# THE EXTENSION OF WIRELESS MESH NETWORKS VIA VERTICAL TAKEOFF AND LANDING UNMANNED AERIAL VEHICLES

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# LIST OF ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| AIS | Automated Identification System |
| AGL | Above Ground Level |
| AFP | Autonomous Flight Package |
| BS | Base Station |
| BLDC | Brushless Direct Current |
| COA | Certificate of Authorization |
| C4ISR | Command, Control, Computers, and Communications for Intelligence, Surveillance, and Reconnaissance |
| CHD | Complex Humanitarian Disasters |
| COASTS | Coalition Operating Area Surveillance and Targeting System |
| COP | Common Operating Picture |
| DO | Distributed Operations |
| DoD | Department of Defense |
| DRDO | Defense Research Development Organization |
| DSL | Digital Subscriber lines |
| EPLRS | Enhanced Position Location Systems |
| ESA | Electronic Steer-able Antenna |
| FAA | Federal Aviation Administration |
| FHL | Fort Hunter-Liggett |
| GMII | Global Maritime Intelligence Initiative |
| GPS | Global Positioning System |

| | |
|---|---|
| GWOT | Global War on Terrorism |
| HFN | Hastily Formed Networks |
| HMMWV | Highly Mobile Multipurpose Wheeled Vehicles |
| IDS | Integrated Deepwater System |
| IEEE | Institute of Electrical and Electronics Engineers |
| IIFC | Inter-agency Intelligence and Fusion center |
| IMO | International Maritime Organization |
| ISPS | International Ship and Port Facility Code |
| ISR | Intelligence, surveillance, and reconnaissance |
| JFMCC | Joint Force Maritime Component Command |
| JIATF-W | Joint Interagency Task Force West |
| JUSMAGTHAI | Joint United States Military Advisory Group Thailand |
| LAN | Local area Network |
| LFA | Lead Federal Agency |
| LOS | Line of sight |
| MAC | Media Access Layer |
| MALSINDO | Malaysia Singapore Indonesia |
| MDA | Maritime Domain Awareness |
| MCK | Mobile Communications Kit |
| MIO | Maritime Interdiction Operations |
| MMEA | Malaysian Maritime Enforcement Agency |
| MOE | Measures of Effectiveness |
| MOP | Measures of Performance |
| MSL | Mean Sea Level |

| | |
|---|---|
| NCW | Network-centric warfare |
| NECC | Naval Expeditionary Combat Command |
| NOC | Network Operations Center |
| NGO | Non-governmental Organizations |
| NKGM | Knowledge Management |
| NLOS | Non-line of Sight |
| NMIC | National Maritime Intelligence Center |
| NORM | Nak-only reliable multicast |
| NPS | Naval Postgraduate School |
| OEF | Operation Enduring Freedom |
| OFDM | Orthogonal Frequency Division Multiplexing |
| OIF | Operation Iraqi Freedom |
| OSPF | Open Shortest Path First |
| OTM | On the move |
| PAN | Portable Area Network |
| PHY | Physical Layer |
| PSI | Proliferation Security Initiative |
| PtMP | Point to Multi-point |
| QDR | Quadrennial Defense Report |
| QoS | Quality of Service |
| RMSI | Regional Maritime Security Initiative |
| RTARF | Royal Thai Air Force |
| RV | Recreational Vehicle |
| SINGARS | Single Channel Air-Ground Radios Systems |

| | |
|---|---|
| SNMP | Simple Network Management Protocol |
| SOLAS | Safety of Life at Sea |
| STOM | Ship to objective maneuver |
| TCP | Transmission Control Protocol |
| TNT | Tactical Network Topology |
| US | United States |
| USCG | United States Coast Guard |
| USN | United States Navy |
| USMC | United States Marine Corps |
| USSR | Union of Soviet Socialists Republic |
| USPACOM | United States Pacific Command |
| USSOCOM | United States Special Operations Command |
| UAV | Unmanned Aerial Vehicle |
| VTOL | Vertical Take Off and Land |
| WLAN | Wireless Local Area Network |
| WAN | Wide area network |
| WAP | Wireless Access Point |
| WCO | World Customs Organization |
| WiFi | Wireless Fidelity |
| WiMAX | Worldwide Interoperability for Microwave Access |
| XML | Extensible Mark-up Language |

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# I. INTRODUCTION

## A. BACKGROUND

### 1. Modern Wireless Networking

The continuing refinement of the Institute of Electrical and Electronics Engineers (IEEE) wireless 802.11 networking standard has enabled the average person to purchase and deploy inexpensive wireless technology. This is turn permits increasingly easy and rapid connection to an expanding cloud of 802.11 wireless local area networks (WLANs). Using these connections, an individual can surf the internet from the local coffee shop, check email while in line at the supermarket and even buy and sell stock while at the car wash. What has caused this proliferation in easily accessible WLANs is not the fact that the technology is extremely wide-reaching but that it is a relatively simple system to set up and then deploy.

Wireless networking in itself is not a new idea. While in a different sense than the way the word is used today, a connection between two handheld radios can be identified as a version of wireless networking. In this case, data is being passed in the form of voice communications. However, with the rise of 802.11 networking technology, there has been a vast increase in the amount of data that can be passed as well as the speeds at which that data traverses the network.

Combined with the ease of usage that is inherent and has been routinely demonstrated with respect to 802.11, capabilities exist that may potentially assist the warfighter during operations in a tactical environment. The greater flow of data to the warfighter allows for better spatial and situational awareness, thereby creating more flexible and robust courses of action to satisfy mission objectives. If a unit is preparing for a specific task, the instantiation of a local WLAN will not only complement the wired infrastructure needed for communications, but increase the quantity and types of data that can quickly and easily be relayed to

the end-user, thus creating an enhanced capability to pass orders (C2), coordinate actions, exchange information, and synchronize actions in terms of a unit's response to an incident.

With a few exceptions, 802.11 technologies are restricted primarily to line of sight (LOS) communications, and thereby limit network coverage to terrestrial line of site within the battle space. Creative employment of 802.11 technologies to enable the widest LOS coverage and access to the warfighter have included mounting wireless access point hardware on mobile platforms such as highly mobile multipurpose wheeled vehicles (HMMWV), balloons, and mobile antenna masts. Each of these solutions accomplishes their desired purpose, to extend wireless network coverage; however, each of these solutions is anchored to the ground and/or requires a significant logistic footprint to transport, maintain, or service. This lack of combined vertical and horizontal mobility, coupled with the aforementioned logistic encumbrance, leaves the warfighter with the requirement of a wireless network extension solution that utilizes a relatively small logistic overhead and is also capable of volume movement in the operations area.

An answer to this shortfall is the equipping of an Unmanned Aerial Vehicle (UAV) with an 802.11 mobile wireless access point, thereby breaking the bonds of terrestrial attachment while simultaneously extending the coverage of the wireless network beyond the LOS of the Network Operations Center (NOC) and proving wireless network access of the tactical user (disadvantaged user) out of the terrestrial line of site of the NOC.

### 2. Mini-Unmanned Aerial Vehicles

Unmanned Aerial Vehicles (UAV) have recently gained wide spread attention as a key enabler to the warfighter. The ability to place a tactical asset in the air with minimal risk to personnel has broadly expanded the commander's array of options in the Joint Operating Area (JOA). Now, the perceived risk of putting an aerial Intelligence Surveillance and Reconnaissance (ISR) platform into a hostile environment is greatly mitigated. Also, due to the removal of a

cockpit from the system, the airframes can be constructed at a greatly reduced size and weight thereby increasing the design flexibility options available to the UAV design team.

The implementation of UAVs spans military organizational strata, from the strategic level incorporating airframes like the Global Hawk (See Figure 1) which can remain aloft for 42 hrs. and employ a payload of 1,960 lbs[1] and the Pioneer (See Figure 2), which can remain aloft for 29 hrs. and employ a payload of 700 lbs,[2] all the way to the tactical level with the introduction of smaller UAVs that can be fielded by maneuver-sized elements such as companies, platoons and squads.


Figure 1    RQ-4A Global Hawk (From: globalsecurity.org).

[1] Global Security.org, <http://www.globalsecurity.org/intell/systems/uav.htm>, (22 May 2006).

[2] Ibid.

Figure 2 Pioneer UAV (From: www.fas.org).

Figure 3 RQ-11A Raven (From: xpda.com).

Figure 4 Boeing ScanEagle (From: www.geocities.com).

These maneuver element sized UAVs such as the RQ-11A Raven (See Figure 3) which can remain aloft for 1.3 hrs, and carry a 4.5 lb[3] and the Boeing ScanEagle (See Figure 4) which can remain aloft for 15 hours and carry a payload of 8 lbs[4]. Most of the UAVs that are employed by maneuver sized units are classified as mini-UAVs.

Mini-UAVs typically fly between 18 and 45 knots and weigh between 1 and 40 pounds (See Figure 5). They have wingspans between 6 inches and 10 feet with maximum ranges being limited by the horizon. Mini-UAVs must maintain line-of-sight (LOS) between the aircraft and the ground station. The small size of these units inhibits the ability to carry satellite communications gear onboard for Over-the-Horizon (OTH) communications. Mini-UAVs are easily supportable with a small footprint and require very little logistical support. These systems are designed to provide an organic UAV capability to small forces such as Special

[3] Global Security.org, <http://www.globalsecurity.org/intell/systems/uav.htm>, (22 May 2006).

[4] Boeing, <http://www.boeing.com/defense-space/military/scaneagle/index.html>, (23 May 2006).

Operations, company, platoon, and squad units.[5] This genre of maneuver elements, also known as Tactical Users, stands to gain numerous benefits from the addition of organic mini-UAV's to their inventories.

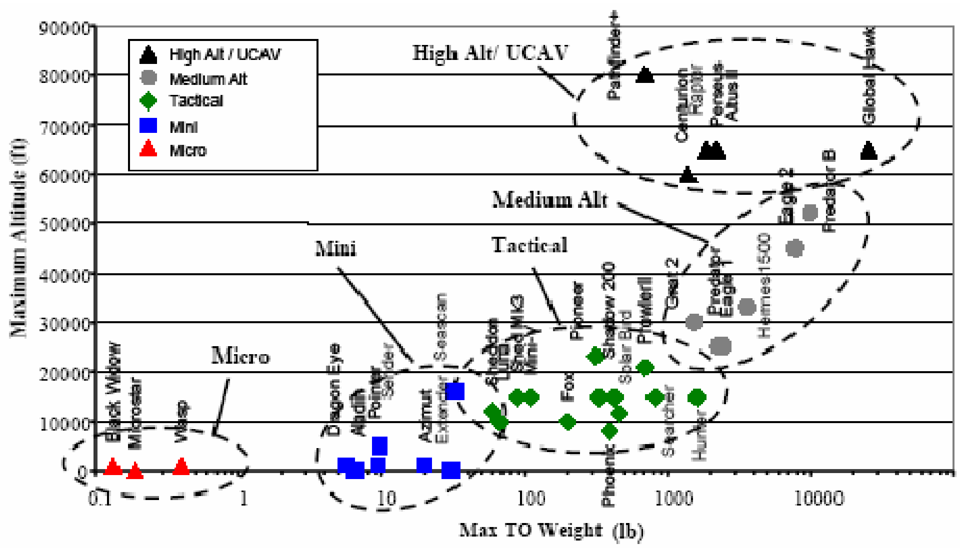


Figure 5 UAV Classification Continuum (From: Weibel).

## B. THE TACTICAL USER

With the emergence of the information enabled combatant, the warfighter has been equipped with a wealth of situational awareness aids, real time targeting tools, and communication channels. Utilizing these different elements requires a greater networking signal footprint, to extend the command and control that the unit commander can provide. As such, there is a greater requirement for the flow of data from the battlefield to the unit commander and, if required, to the mission level or even theatre level commander.

The tactical user label spans a wide envelope of descriptions. The light infantryman is an obvious candidate for this label, but Special Operations Forces (SOF), Vessel Boarding Search and Seizure (VBSS) parties, Maritime Interdiction Operations (MIO) teams, and constabulary forces also fit well in this wide description.

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[5] Weibel, p. 2.

However, the JOA is an environment that is harsh and unforgiving. A deployment of existing technologies, such as COTS 802.11 technology, requires a robust platform that can withstand the ever-changing environmental conditions that may be experienced throughout the world. Fortunately, the commercial world has realized the requirement for these robust platforms and has designed and fielded equipment capable of operating in the adverse environments found in the JOA.[6]

## C. AERIAL IMPROVISED EXPLOSIVE DEVICE (AIED) THREAT

As early as January 2006, AIEDs were reportedly being employed by insurgents in Iraq[7] to bring down low flying helicopters. The evolution of this threat naturally points toward enabling a COTS Remote Controlled (RC) aircraft or improvised UAV with an explosive payload to be used as an extended range AIED. This implementation is advanced by the increasing sophistication of RC Aircraft digital transmitters and receivers, the reduction in size and weight of IP based technologies, the availability of commercial autonomous flight packages and the presence of open source software to enable the integration of autonomous flight components into RC aircraft which may permit the flight of AIEDs in nearly any environment by an enemy combatant not co-located with the AIED. A brief search on the internet yields a detailed description of converting an RC Helicopter to a computer controlled WiFi linked UAV.[8]

## D. COASTS 2006

### 1. Background

The Coalition Operating Area Surveillance and Targeting System (COASTS) programmatic concept is an effort to respond to the recognized requirement to produce a rapidly deployable, low cost, system to support multi-

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[6] COSTS 2006 CONOPS, p. 2.

[7] DefenseTech.org, <http://www.defensetech.org/archives/002090.html>, (19 August 2006).

[8] Orange, <http://perso.orange.fr/pascal.brisset/chromicro/doc/chromicro.html>, (17 September 2006).

national data sharing by fielding a robust IP network based on wired and wireless COTS technologies. This fielded network provides a platform from which various COTS C4ISR technologies are evaluated for JOA implementation and integration by the warfighter.

Most Naval Postgraduate School (NPS) field experiments are, due primarily to their affiliation with activities that conduct such operation, primarily CLASSIFIED in nature. The COASTS 2006, test, and evaluation platform is, by design, an UNCLASSIFIED effort to provide a venue for coalition partners, domestic constabulary agencies, and Non-Governmental Organizations (NGO). This premeditated adherence to an unclassified infrastructure allows the integration of the above agencies into experimentation in accordance with Chief of Naval Operations (CNO) Guidance, 2006.

#### 2. Purpose

COASTS 2006 expanded upon the original field experiment conducted during COASTS 2005's deployment to Wing 2, Lop Buri, Thailand. In 2006, the network team researched equipment relative to low-cost, commercially available solutions while integrating each technology and capability into a larger system of systems in support of tactical action scenarios.

The May 2006 demonstration was an air, ground, and water-based scenario, occurring just north of Chiang Mai, Thailand. The scenario (See Figure 6) encompassed first-responder, law enforcement, counter-terrorism, and counter-drug objectives.

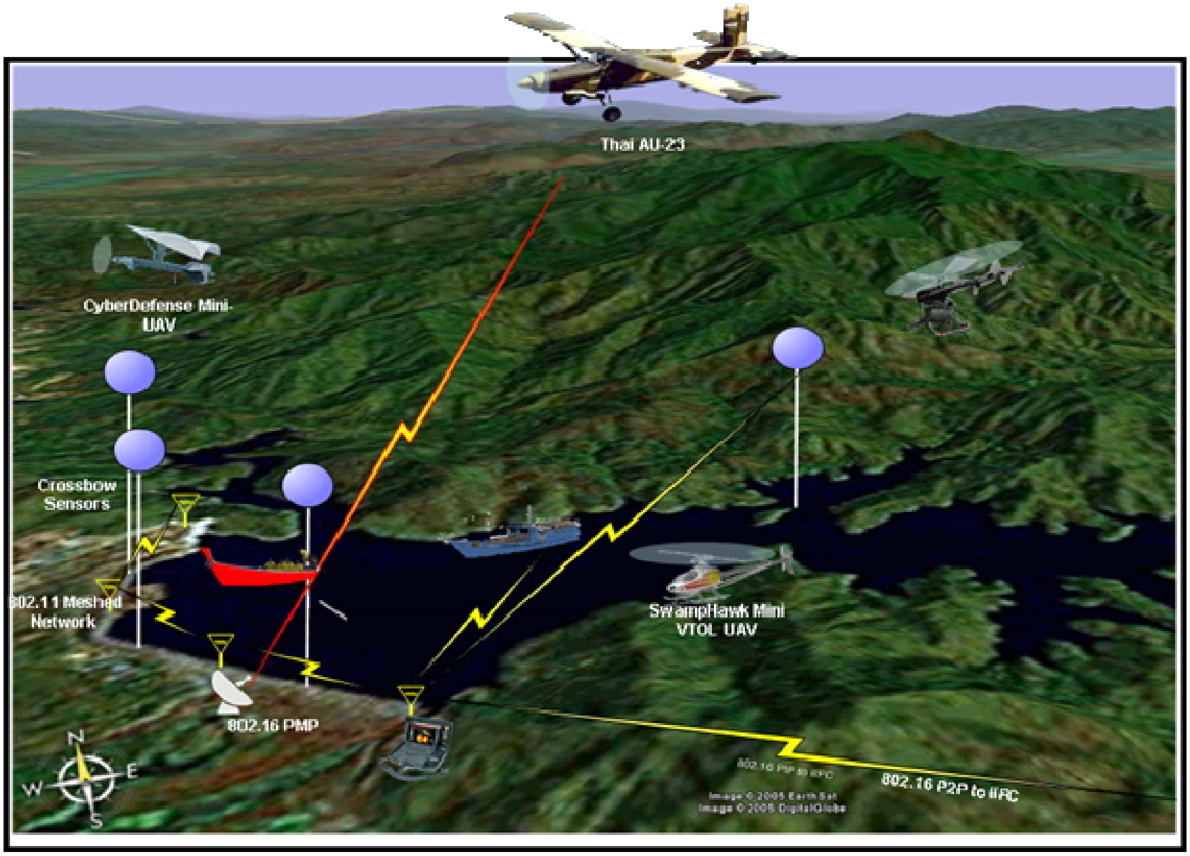


Figure 6 COASTS Scenario Topology (From: Ehlert, 2006).

The tactical information being collected from the scenario was fused, displayed, and distributed in real-time to local (Chiang Mai), theater (Bangkok), and global (Alameda, California) command and control (C2) centers. This fusion of information lead to the validation of using wireless communication mediums to support redundant links of the National Information Infrastructure, as well as the test and evaluation of the 'last mile' solution for the disadvantaged user. Continuing with COASTS 2005's research theme, COASTS 2006 again: (1) examined the feasibility of rapidly-deploying networks, called "Fly-away Kits" (FLAK) and (2) explored sustainable considerations with respect to a hostile climatic (temperature, humidity, wind, etc.) environment. Network improvements included the testing and evaluation of new 802.11 mesh WLAN equipment, the refinement of a jointly-developed (NPS and Mercury Data Systems) 3-D topographic shared situational awareness (SSA) application called C3Trak,

enhanced unattended ground and water-based sensors, new balloon and unmanned aerial vehicles (UAV) designs, portable biometric devices, portable explosive residue detecting devices, and revised operational procedures for deployment of the network.[9]

### 3. COASTS 2006 Tactical Implementation

Through the use of all of the elements involved with the COASTS experiment the final objective is to enable the soldier or unit on the ground with complete spatial awareness of the specific battlespace. Using a rapidly deployable WLAN mesh network, the user can integrate his/her communication device into the network via several different methods which would include:

802.11b/g

802.16 Orthogonal Frequency Division Multiplexing (OFDM)

Satellite Communications (SATCOM)

Situational Awareness Software

Wearable Computing Devices

Personal Navigation Monitors (PNM)

Air and Ground Sensors

Mobile/Fixed Command and Control Platforms.

All of these different methods would mesh seamlessly so the user could identify, communicate, and ultimately operate with the other units on the ground as well as remain in contact with the commanders removed from the battlefield and even commanders who are removed from the theatre.

[9] COASTS 2006 CONOPS, pp. 3-4.

The end objective for the overall COASTS project is to employ modern technology such that the maximum amount of force can be brought to bear while providing the maximum amount of battlefield awareness in conjunction with the smallest amount of support.[10]

## E. THESIS OBJECTIVES

The COASTS 2006 field experiment is utilizing various advances in 802.11 technologies that permit a rapidly formed mesh networks via COTS equipment. In addition, the area of operations (AO) is an environmentally adverse location so the equipment being employed has been designed to withstand the hostile conditions expected. However, what has not been examined in detail is the effect that the varying physical and environmental factors might have on the 802.11 signal, and the performance of a VTOL UAV equipped with 802.11 technologies.

The goal of this thesis is to build upon pre-existing 802.11 IEEE standard applications in an urban, signal-friendly setting, and apply the standard to a COTS RC Helicopter UAV surrogate in a tactical and operational situation. This exploration will help increase the understanding of how 802.11 coverage might be extended by a VTOL UAV. Concurrently, research will be conducted to identify systematic queues to AIED production and potential interdiction techniques of an AIED as it is employed against a target.

[10] COASTS 2006 CONOPS, pp. 3-4.

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# II. TECHNOLOGICAL BACKGROUND

## A. MESH DYNAMICS MESHED 802.11 STRUCTURED MESH NETWORKS

### 1. Introduction

The ability to deploy a high performance wireless network that is not only transparent to the client but provides robust, mobile, radio and IEEE protocol while providing quality of service assurance is very advantageous. The military community deploys in fixed and expeditionary infrastructures that require the distribution of digital information to support battlefield preparation and battlefield situational awareness.

The advent of digital sensor networks; UAV Command and Control, Intelligence, Surveillance and Reconnaissance (C2ISR) systems, Blue Force tracking, and the increased need for imagery data require robust digital wireless networks. These networks need to be auto-configurable and scalable under a single control layer.

The data and communication network complexity of a rapid deployment force would resemble that of a Mobile Area Networks (MAN) with static and mobile Wireless Local Area Networks (WLAN), under which numerous Portable Area Networks (PAN) exist. The MAN would represent the "region of interest" and could/would be 100% wireless or consist of several "wired" operation centers with a hybrid of wireless back hauls and WLANs. WLANs would be established within the operational unit. PANs would be established to support sensor networks, inter-squad communications, etc. WLANs and PANs could be highly mobile and dynamic in nature, and potentially would extend beyond outside of direct MAN connectivity.[11]

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[11] F. Acosta, US High Performance Mesh. Santa Rosa: 2005.

### 2. The MeshDynamics Meshed Network Architecture

Cost effective wireless coverage on a large scale requires that the mesh must be able to provide sufficient bandwidth to clients many “hops” away from the Ethernet feed. Therein lay inherent limitations of mesh products which use one radio for the backhaul. The chief limitation being that One-Radio Ad Hoc Mesh architecture does not scale.

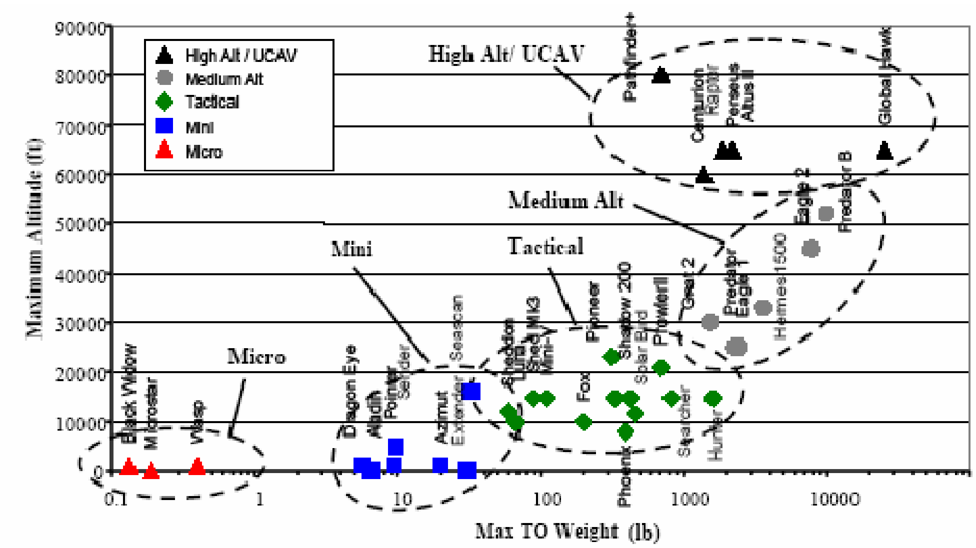


Figure 7 MeshDynamics multi-radio backhaul Comparison (From: Acosta).

In a single radio wireless backhaul, all backhaul radios must “talk” on the same channel (see Figure 7). However, a radio cannot send and receive at the same time. When data is to be relayed across multiple access point segments it must be received by one backhaul radio and then re-transmitted by that backhaul radio to be received by another downstream backhaul radio.

During this relay, nearby radios have to be quiet; since all radios are on the same channel and therefore are a source of interference. This receive-send-receive process used by one radio backhauls limits overall performance, and can result in bandwidth loss and increased latency of up to 50% per hop.

### 3. Structured Mesh™ Uses a 2-Radio Backhaul

Two mesh architectures are shown in Figure 8 below. Most mesh products are a variant of the approach shown on the left. One radio services clients (pink) while the other radio (blue) forms a single radio ad hoc backhaul mesh. The radios operate in non interfering bands: 2.4 GHz (pink) for service and 5.8 GHz (blue) for the backhaul. Note that the wireless backhaul is still a single radio - only one radio (blue) is part of the backhaul. Packets share bandwidth at each hop along the path with other interfering mesh backhauls - all operating on the same channel - because it is a single radio wireless backhaul.

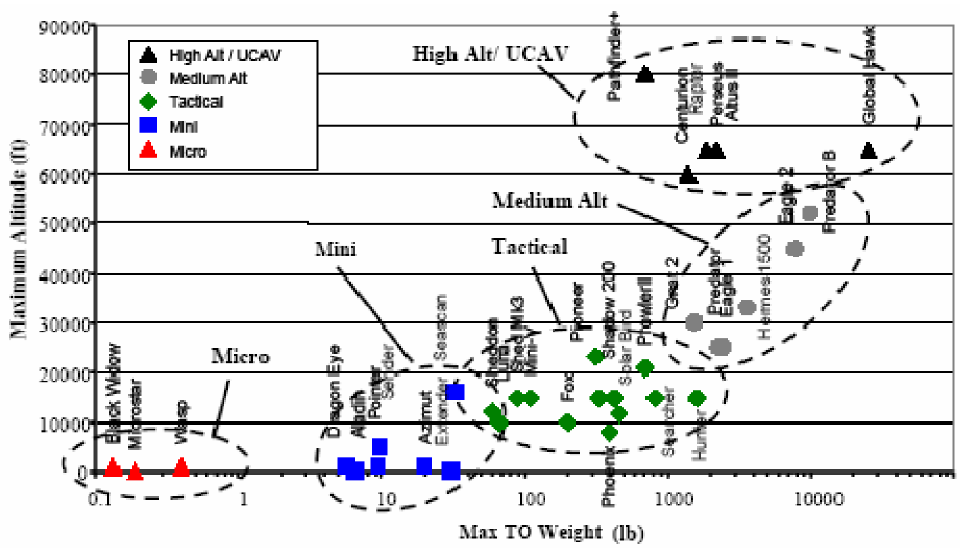


Figure 8 MeshDynamics multi-radio backhaul Simultaneous Send and Receive (From: Acosta).

MeshDynamics Mesh Products have two backhaul radios (for uplink/downlink) and a third 2.4GHz service radio. Both the backhaul up link and down link "talk" on different channels. Bandwidth degradation effects endemic to single radio backhauls are eliminated - each radio link operates independently and simultaneous send/receives are now possible. The separate uplink and

downlink emulates wired switch stacks. This architecture supports scalable networks. Minimal performance degradation is experienced, even over several WAP segments.

In the unlicensed space, interference from other radios is a fact of life. Reduced performance by operating on a "polluted" channel is especially significant in dense metro areas. In 1-radio backhauls all radios share the same channel. Interference on that channel affects the entire network. In contrast, a 2-radio backhaul is more agile: the backhaul radios can switch to other channels to mitigate local interference sources.

### 4. Modular Approach Supports Extendibility

The MeshDynamics Modular Mesh framework is purposely built to ensure interoperability between members of the product family. Modules form a network even if backhaul operate in different frequency bands.

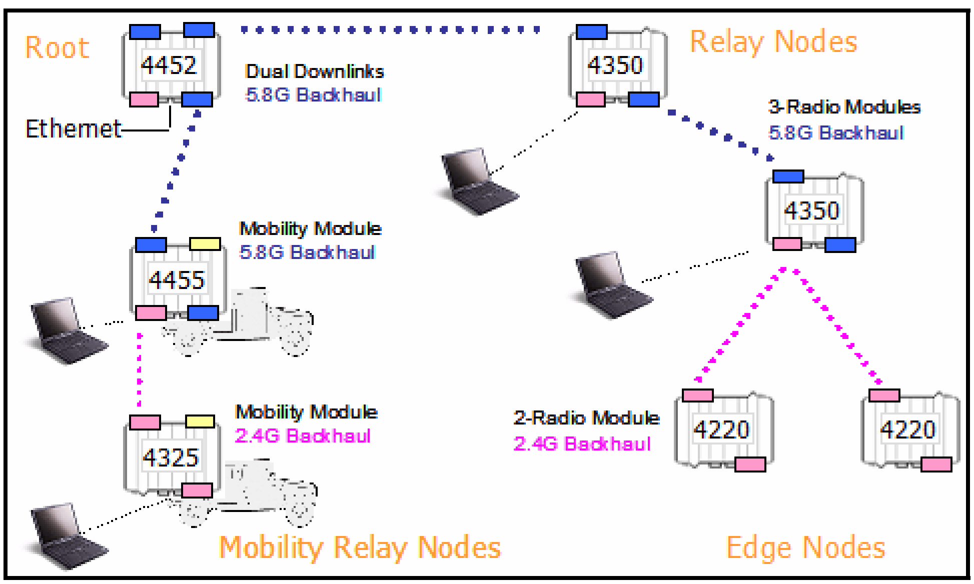


Figure 9 Modular Mesh Interoperable Network (From: Acosta).

As an example (See Figure 9), the two mobile nodes above communicate with each other, though they are operating on different backhaul bands. The

"service" radio of node 4455 is acting as the parent downlink for node 4325. Also edge nodes 4220 connects with relay node 4350 through the service radio.

Since 2.4GHz has more range than 5.8GHz radios, a 2.4GHz backhaul is preferable in low client density situations (such as rural areas) or at edges of the network where the interference is low. Interference increases with increasing client densities (as in urban areas). The 2.4GHz edge node (4220) does not become obsolete: it may be field upgraded to a 3-Radio 5.8GHz backhaul + AP (4350). The 4350 unit may be field upgraded to a 4-radio module if additional downlinks (4452) or an additional AP (4458) is needed. Other mesh products have not been designed with this level of flexibility in mind.[12]

Due to the stated strengths of the Modular Mesh system, it was selected for implementation by the COASTS 2006 project. As such, and to maintain interoperability within the mesh, a MD mobile access point was selected as the 802.11 Wireless Access Point (WAP) payload for the VTOL UAV surrogate.

## B. ROTARY UAV SURROGATE

### 1. Airframe

Due to the commercial shipping constraints of Petroleum, Oil and Lubricant (POL) containing vehicles, and the transpacific voyage that the VTOL UAV surrogate was to undergo in support of the COASTS 2006 experiment, a decision was made very early on in the project to pursue an electric powered solution. This decision, and the dimensional baggage shipping constraints placed on commercial airline traffic, helped to scope market research, bound payload restrictions, and define airframe size.

Based on market research, the majority of the COTS helicopter models at the upper end of the size scale were appropriate. Because of the payload

[12] F. Acosta "Why Structured Mesh?." Mesh Dynamics Structured Mesh Technology. Mesh Dynamics. <http://www.meshdynamics.com/WhyStructuredMesh.html>, (26 August 2006).

requirements, and therefore the required power needed, a very stiff airframe/structure was desired, so a model with a carbon fiber construction was chosen.

### 2. Power Plant

The selection of a vehicle's prime mover selection, be it an aircraft or an earthbound platform, plays a major role in vehicle design. With that in mind, extensive market research was performed to match power, weight, and operating characteristics of the perspective payload, airframe and battery configurations with the appropriate motor. Market research was performed and two general types of COTS electric motors were available; brushed and brushless.

In a conventional (brushed) DC-motor, the brushes make mechanical contact with a set of electrical contacts on the rotor (called the commutator), forming an electrical circuit between the DC electrical source and the armature coil-windings. As the armature rotates on axis, the stationary brushes come into contact with different sections of the rotating commutator. The commutator and brush-system form a set of electrical switches, each firing in sequence, such that electrical-power always flows through the armature-coil closest to the stationary stator (permanent magnet.)

In a brushless DC (BLDC) motor, the brush-system/commutator assembly is replaced by an intelligent electronic controller. The controller performs the same power-distribution found in a brushed DC-motor, only without using a commutator/brush system. The controller contains a bank of metal-oxide-semiconductor field-effect transistor (MOSFET) devices to drive high-current DC power, and a microcontroller to precisely orchestrate the rapid-changing current-timings. Because the controller must follow the rotor, the controller needs some means of determining the rotor's orientation/position (relative to the stator coils).[13]

[13] Wikipedia, <http://en.wikipedia.org/wiki/Brushless_DC_Electric_Motor>, (15 June 2006).

BLDC motors offer several advantages over brushed DC-motors, including higher reliability, reduced noise, longer lifetime (no brush erosion), elimination of ionizing sparks from the commutator, and overall reduction of electromagnetic interference (EMI.) BLDC's main disadvantage is higher cost, which arises from two issues: First, BLDC motors require high-power MOSFET devices in the fabrication of the electronic speed controller. Brushed DC-motors can be regulated by a comparatively trivial variable-resistor (potentiometer or rheostat), which is inefficient but also satisfactory for cost-sensitive applications. BLDC motors need a more expensive integrated circuit, called an electronic speed controller, to offer the same type of variable-control. Second, when comparing manufacturing techniques between BLDC and brushed motors, many BLDC designs require manual-labor, to hand-wind the stator coils. On the other hand, brushed motors use armature coils which can be inexpensively machine-wound.

BLDC motors are considered more efficient than brushed DC-motors. This means for the same input power, a BLDC motor will convert more electrical power into mechanical power than a brushed motor. The enhanced efficiency is greatest in the no-load and low-load region of the motor's performance curve. Under high mechanical loads, BLDC motors and high-quality brushed motors are comparable in efficiency[14].

Because of the efficiency and performance characteristics of BLDC motors, a BLDC was selected as the power plant for the VTOL UAV surrogate described in this thesis.

### 3. Electronic Speed Controller

An Electronic Speed Controller (ESC) is a stand-alone unit which plugs into the receiver's throttle control channel and interprets control information in a way that varies the switching rate of a network of field effect transistors (FET). This switching allows for much smoother and more precise variation of motor speed in a far more efficient manner than the mechanical type with a resistive

[14] Wikipedia, <http://en.wikipedia.org/wiki/Brushless_DC_Electric_Motor>, (15 June 2006).

coil and moving arm once in common use. In rotary flight, it is desirable to maintain a constant rotor head RPM in most cases, and most modern ESCs provide constant speed functionality to enable this option. The ESC adjusts voltage output (RPM) and current (torque) to maintain rotor RPM at a constant rate as collective settings (collective pitch) are varied. This produces stable and predictable flight performance. Lithium Polymer (LiPO) ESC models also provide for low voltage cutoff, which is essential for use with LiPo battery packs to prevent damage, and possible combustion of the battery packs.

It is essential that the ESC be matched with the type of motor (brushed or brushless) and the motors capacity. As the motor selected for the surrogate VTOL UAV is capable of drawing >40A of current, the ESC must be rated to handle the current and associated heat load to prevent damage to the ESC and enable the peak performance of the motor in the presence of both moderate and high ambient temperature operations.

#### 4. Receiver

As the name of this component suggests, it acts as the wireless receiving station for the signal that is transmitted from the operator's radio remote control. Receivers in the market place today operate 27, 72, 75 MHz, and 2.4 GHz. In the 27, 72, and 75 MHz frequencies channels are spaced out at 20 kilo hertz (KHz) intervals to allow for multiple paired receiver / transmitter users to operate in discrete channels without interference. The Federal Communications Commission limits the output power in the 27, 72, and 75 MHz frequencies to 750 miliwatts (mW). 2.4 GHz models, along with their transmitters were not considered for this experiment, as the many technologies in the COASTS 2006 experiment operated in the 2.4 GHz space. However, interference was not a likely worry in the 2.4 GHz space, as FCC regulations require, as a condition on their certification, that devices not interfere with other certified devices in that frequency, but providing as clean a Radio Frequency (RF) space in experimental conditions as possible was deemed desirable.

For receivers used in helicopter applications, pitch, collective, yaw / gyro, throttle, cutoff and receiver power channels are required. Because of this requirement, receivers with fewer than six channels were not considered for installation in the VTOL UAV surrogate.

### 5. Servos

The primary function of a servo is to convert an electrical signal into a mechanical output. The mechanical output in the case of rotary flight is control surface input. Because of the near continuous, minute, and robust control inputs required for controlled rotary flight, specific performance characteristics of servos used in RC helicopter applications exist. Servos must be responsive (< .2 sec/60$^{O}$) and powerful (>120 in oz. torque). A wide variety of servos in this range exists and is represented broadly by two classes; digital and standard. The digital servos operate in a more precise and predictable manner and are generally more fault resistant than the standard analog types. Because of this positive trait, digital servos were selected for the VTOL UAV surrogate.

### 6. Heading Gyro

Heading gyros work with the yaw servo to detect and dampen or nearly eliminate helicopter movement in the yaw axis (defined as planar motion about the main rotor shaft). This is accomplished by an accelerometer in the heading gyro detecting motion in the yaw axis and sending a compensating signal to the yaw servo to correct for the deviation. Not all motion in the yaw axis is unwanted though, so the gyro monitors the signal from the yaw channel of the receiver to allow specific frequencies of yaw when a control signal is detected from the receiver. Many gyro units have a heading hold feature which also dampens the yaw signal from the receiver to prevent over controlling and pilot induced oscillations (PIO). This feature is desirable for the novice RC helicopter pilot as it provides more yaw controllability and therefore a gentler operator learning curve.

## 7. Batteries

There are three major chemistry types used in constructing a rechargeable battery. The first one is called Nickel Cadmium (NiCd). NiCd batteries are relatively inexpensive, but they have a number of negatives. NiCd batteries need to be fully discharged after each and every use. If they aren't, they will not discharge to their full potential (capacity) on subsequent discharge cycles, causing the cell to develop what's commonly referred to as a memory. Additionally, the capacity per weight (also known as "energy density") of NiCd cells is generally less than Nickel Metal Hydride (NiMH) or Lithium Polymer (LiPo) cell types as well. Finally, the Cadmium that is used in the cell is quite harmful to the environment, making disposal of NiCd cells an issue. For thisreason several countries in Europe have banned NiCd batteries. This ban accelerated the demand for alternative cell types, and the first to really answer the call was NiMH.

NiMH cells have many advantages over NiCd cells. With the removal of Cadmium from the cell, the NiMH cells were able to fill the need for industrial and hobby-grade batteries over a much broader market. NiMH cell manufacturers were also able to offer significantly higher capacities in cells approximately the same size and weight of comparable NiCd cells. NiMH cells have an advantage when it comes to cell memory too, as they do not develop the same performance issues as a result of improper discharge care.

Lithium Polymer cells are the newest and most revolutionary cells to come to market. LiPo cells typically maintain a more consistent average voltage over the discharge curve when compared to NiCd or NiMH cells. Add to that the higher nominal voltage of a single LiPo cell (3.7V versus 1.2V for a typically NiCd or NiMH cell), making it possible to have an equivalent or even higher total nominal voltage in a much smaller package. LiPo cells also typically offer very high capacity for their weight, delivering upwards of twice the capacity for sometime ½ the weight of comparable performance NiMH cells and packs. However, with so much energy packed into such a small space, there are some

important safety measures to take when dealing with LiPo cells. A LiPo cell needs to be carefully monitored during charging as overcharging a LiPo cell (to beyond 4.2v), or the charging of a physically damaged or over discharged cell (discharged to below 3.0v under load) can be a potential fire hazard.

Care must not only be taken when charging LiPo cells, but when discharging them as well. A LiPo pack should never be over-discharged below 3.0v per cell under load, and ESC programmed to provide the proper low voltage cutoff for the pack (for example, a 9v cut off for a 3 series LiPo pack) must be used. While these seem like major deterrents to using a LiPo battery, these usage guidelines are quickly becoming well known and are typically well outlined in the instruction manuals included with most LiPo packs, ESCs and LiPo chargers.[15] With all of their performance benefits, lithium polymer battery packs are the power sources that were selected for the VTOL UAV surrogate.

### 8. Transmitter

Modern Radio Control transmitters have become very versatile. Current high end versions employ frequency hopping techniques to prevent potentially catastrophic RF interference, and many have sophisticated onboard computers. The most expensive models utilize high speed processors and run versions of the Microsoft Mobile PC operating system with full color displays. With some models having over 15 control knobs and switches, it is difficult to readily identify the most appropriate model for use. However, the criteria for multiple programmable models, helicopter modes, a minimum of 4 selectable multi-position switches, onboard flight timing, and an interface to a computer simulator do exist. Based on these criteria, a well suited radio was selected.

### 9. Support Equipment

Flight simulation software, tools, chargers, calibration and diagnostic equipment, repair materials, lubricants, and solvents are all required to field the

[15] "RC Airplane Battery Basics." Red Rocket Hobby Shop. <http://www.redrockethobbies.com/RC_Airplane_Battery_Basics_s/263.htm>, (27 August 2006).

surrogate VTOL UAV.  Each item, essential in its function, was painstakingly identified and researched to ensure its necessity and applicability to the project.

## C. HELICOPTER AERODYNAMICS

For the purpose of this thesis, a general understanding of helicopter performance in the presence of different atmospheric conditions is necessary to identify the unique challenges associated with the selection of many aspects of the surrogate UAV and account for the performance results discussed in Chapter VI.  A much more in depth discussion of the mysteries of rotary aerodynamics could be undertaken.  This discussion however, will be limited to the effects of atmospheric conditions on helicopter performance.  The following discussion is taken from The Basic Helicopter Handbook.[16]

### 1. Helicopter Performance

Assuming that a helicopter engine and all components are operating satisfactorily, the performance of the helicopter is dependent on three major factors:

Density altitude (air density)

Gross weight

Wind velocity during takeoff, hovering, and landing

For the purposed of this thesis, only air density and its effects on rotary aerodynamics, specifically lift, will be discussed.

#### *a. Air Density*

Air, like liquids and other gases, is a fluid. Because it is a fluid, it flows and changes shape under pressure. Air is said to be "thin" at high altitudes; that is, there are fewer molecules per cubic foot of air at 10,000 feet than at sea level. The air at sea level is "thin" when compared to air compressed to 30

[16] United States. Federal Aviation Administration, Basic Helicopter Handbook. Aviation Supplies & Academics, 1978.

pounds of pressure in an automobile tire. A cubic inch of air compressed in an automobile tire is denser than a cubic inch of "free" air at sea level.

For example, in a stack of blankets, the bottom blanket is under pressure of all blankets above it. As a result of this pressure, the bottom blanket may be squeezed down until it is only one-tenth as bulky as the fluffy blanket on top. There is still just as much wool in the bottom blanket as there is in the one on top, but the wool in the bottom blanket is 10 times denser. If the second blanket from the bottom of the stack were removed, a force of 15 pounds might be required to pull it out. The second blanket from the top may require only 1 pound of force. In the same way, air layers near the earth's surface have much greater density than air layers at higher altitudes. Simply stated, the lower the elevation of the earth's surface, the greater the density of the air layers. For example, the layer of air at sea level would be denser than the layer of air at the earth's surface at Denver, Colo., at approximately 1 mile above sea level.

The above principle may be applied in flying aircraft. At lower levels the rotor blade is cutting through more and denser air, which offers more support (lift) and increases air resistance. The same amount of power, applied at higher altitudes where the air is thinner and less dense, propels the helicopter faster.

***b. Density Altitude***

Density altitude refers to a theoretical air density which exists under standard conditions of a given altitude. Standard conditions at sea level are:

Atmospheric pressure - 29.92 in. of Hg (inches of mercury)

Temperature - 59° F. (15° C.)

Standard conditions at any higher altitude are based on:

Atmospheric pressure (reduced to sea level): 29.92 in. of Hg

Temperature: 59° F. (15° C.) minus 3 1/2° F. (2° C.) per 1,000 feet elevation

For example, if the atmospheric pressure (reduced to sea level) at an airport located 5,000 feet above sea level is 29.92 inches of mercury and the temperature is 59° - (3.5° x 5) = 41.5° F. (5° C.), the air density is standard at that altitude. (The actual barometric pressure at an elevation of 5,000 feet under these conditions would be approximately 24.92 inches of mercury since atmospheric pressure decreases approximately 1 inch per 1,000-foot increase in altitude. The average temperature decrease per 1,000-foot increase in altitude is 3.5° F.).

### *c. Effect of High Density Altitudes on Helicopter Performance*

High elevations, high temperatures, and high moisture content, all of which contribute to a high density altitude condition, lessen helicopter performance. Because the difference between power available and power required is so small for a helicopter, particularly in hovering flight, density altitude is of even greater importance to the helicopter pilot than it is to the airplane pilot. Helicopter performance is reduced because the thinner air at high density altitudes reduces the amount of lift of the rotor blades.

# III. SELECTION OF METRICS

## A. COASTS 2006 MEASURES OF EFFECTIVENESS (MOE) AND MEASURES OF PERFORMANCE (MOP)

In order to make logical decisions and choices in network development, criteria to measure the value or relative importance of aspects of the network is required. This is an essential pre-requisite for system analysis and predictive study. Both the client (customer / user) and network designer have such measures, and these measures are related. MOE represent the user view, usually annotated and of qualitative nature. They describe the customers' expectations of functional performance and should be viewed as the voice of the user.

MOP are the corresponding view of the designer; a technical specification for a product. Typically MOP are quantitative and consist of a range of values about a desired point. These values are what a designer targets when designing the network, by changing components, protocols and infrastructure locations, so as to finally achieve the qualities desired by the user. Both the MOE and the MOP can be constructed as a hierarchy diagram. Each horizontal level of the hierarch represents 100% of the effectiveness or performance. COASTS MOE and MOP were evaluated by the Data Collections team to most efficiently gather and analyze the data associated with each measure. In the following hierarchy diagrams, each node is identified and MOE and MOP are listed in an attempt to specifically communicate each node's data collection needs.[17]

## B. 802.11 ACCESS POINT

The MOE in the COASTS 2006 experiment were utilized to select, based on market research, a wireless mesh infrastructure that met or exceeded a list of

[17] COASTS 2006 CONOP, p. 29.

six specific MOE (see Figure 10). The COTS solution selected, ultimately the MeshDynamics MD4000 series, met or exceeded each MOE which was reflected in an overall MOE score of 1.0.

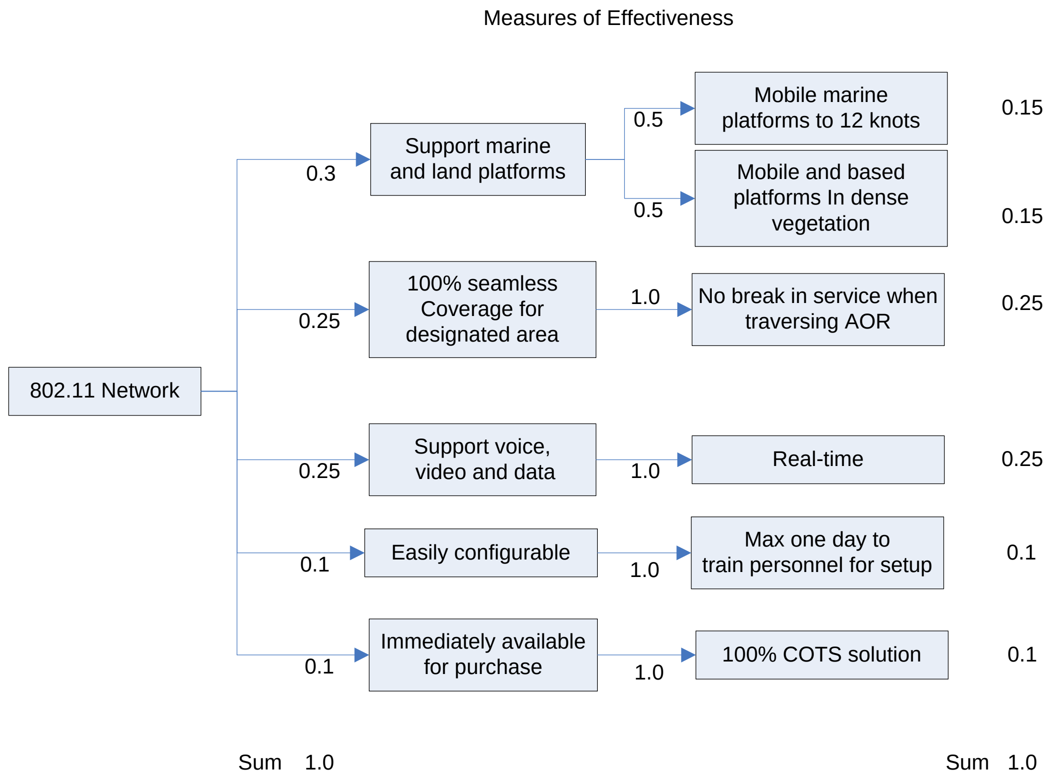


Figure 10 802.11 Measures of Effectiveness (From: COASTS 2006 CONOPS)

The evaluation of network performance is not a straight forward endeavor. The type of data to be passed over the network and the implementation of the network both drive, and in some cases with competing interests, the evaluation of a network's effectiveness.

After considering the protocols to be employed on the 802.11 network, the types of data to be passed, and the geographical spread of the network to be evaluated, the data collections team and the network team concluded that the key measures to collect and analyze were throughput, latency, and quality of signal (QoS). (see Figure 11 below)

Upon further investigation, the MD 4000 series structured mesh utilized software to optimize signal quality based on signal strength and acknowledgment timing. Due to this intelligent optimization performed by the MD hardware, QoS was dropped as an observed MOP as it remained well above the desired threshold throughout initial testing. Latency was also observed to be well above desired thresholds as well, however, research within the experiment required that latency data be collected analyzed.

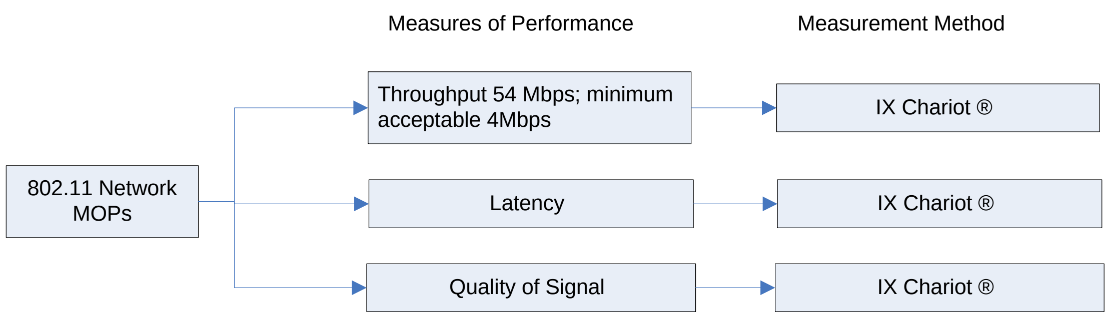


Figure 11 802.11 Measures of Performance (From: COASTS 2006 CONOPS).

### 1. Throughput

For packet-switched networks, throughput is the rate at which a computer or network sends or receives data. It is therefore a good measure of the channel capacity of a communications link, and connections to the internet are usually rated in terms of their bit rate, how many bits / bytes they transmit per second (bit/s).

However, throughput is a poor measurement of perceived speed, which is mostly based on the speed of requests made or responsiveness. As such, responsiveness has far less to do with throughput than latency. To illustrate this,

consider a truck full of magnetic tape en route from California to New York. The time or latency it takes to deliver the data may be several days, but the amount or throughput of data delivered will exceed the throughput of a broadband connection. In contrast, the broadband connection, which has a throughput many times less than that of the truck, has a relatively low latency and can deliver smaller amounts of data much faster.[18] For a user wishing to view streaming video at a at a palatable frame rate (>16 fps), or a pair of persons carrying on a VoIP conversation (no voice delay), low latency is essential for coherent communication. However, in both of these cases, it is also essential for the throughput to be adequate to pass data at a rate which prevents the packets from "piling up" at either end of the transmission.

Normally throughput and latency are opposed goals. To improve latency one generally desires to increase how much the computer checks to see if one is trying to interact. This checking overhead slows down data transfer. However, there is one very common exception to this rule. Network protocols and programs tend to synchronize both ends regularly. If these synchronizations are slow, then throughput can suffer tremendously.[19]

### 2. Latency

Latency in a packet-switched network is measured either one-way (the time from the source sending a packet to the destination receiving it), or round-trip (the one-way latency from source to destination plus the one-way latency from the destination back to the source). Round-trip latency is more often quoted, because it can be measured from a single point. Note that round trip latency excludes the amount of time that a destination system spends processing the packet. Many software platforms provide a service called ping that can be used

[18] Wikipedia, <http://en.wikipedia.org/wiki/Throughput>, (19 July 2006).

[19] Ibid.

to measure round-trip latency. Ping performs no packet processing; it merely sends a response back when it receives a packet (i.e., performs a no-op), thus it is a relatively accurate way of measuring latency.

Where precision is important, one-way latency for a link can be more strictly defined as the time from the start of packet transmission to the start of packet reception. The time from the start of packet reception to the end of packet reception is measured separately and called "transmission delay." This definition of latency is independent of the link's throughput and the size of the packet, and is the absolute minimum delay possible with that link.

However, in a non-trivial network such as that being tested, a typical packet will be forwarded over many links via many gateways, each of which will not begin to forward the packet until it has been completely received. In such a network, the minimal latency is the sum of the minimum latency of each link, plus the transmission delay of each link except the final one, plus the forwarding latency of each gateway.[20]

Latency on the COASTS 2006 802.11 network was collected and recorded via Ixia's IxChariot console.

## C. ENVIRONMENTAL OBSERVATIONS

One of the inherent strengths of the COASTS 2006 experiment is its ability to carryout experiments in a wide array of climatic conditions. From the dry cold environment of Fort Hunter-Liggett, CA in December, to the hot and humid conditions of northern Thailand in March, the project was able to observe and gather data on the deployed network in each of these conditions and many variations in between. The items described in this section would more aptly be described as metrics rather than measures of effective or performance as there are no threshold values that we associate a positive or negative outcome with.

[20] Wikipedia, <http://en.wikipedia.org/wiki/Network_Latency>, (19 July 2006).

On the contrary, these measures associated with environmental factors contribute to the body of data that will undergo analysis used to discover potential correlations between the MOP and the environment.

These measures include:

- Temperature
- Barometric Pressure
- Relative Humidity
- Wind velocity

These measures will be input into equations that will produce barometric altitude, and density altitude. Each of these measurements, and the resultant altitude calculations are collected and logged in the Kestrel Hand held weather station.

# IV. UAV SURROGATE TEST PLATFORM CONSTRUCTION METHODOLOGY

## A. INTRODUCTION

In evaluating the construction of the UAV Surrogate test platform, the author endeavors to accomplish two goals:

1. Test and evaluate the functionality of a VTOL UAV as a wireless network extension platform.

2. Gain insight into the potential systematic queues of AIED construction, operation, and control.

For the scope of this project, a UAV Surrogate was constructed that was capable of employing an autonomous flight package (AFP) but was tested utilizing remote control. The choice to pursue a remotely piloted air frame, vice autonomous control for this research, stemmed from two distinct complications.

Primarily, the implementation of an autonomous flight package in a helicopter, while possible, is by no means trivial. Commercial hardware and open source software do exist which make autonomous helicopter flight achievable, however the integration of this technology presented a broadening of the scope of this project which presented an untenable outcome. The capability of the airframe to support the weight of the package was addressed, and the AFP implementation time and skills were estimated and included in the systematic evaluation to target AIED construction.

Secondarily, the ability to operate an autonomous airframe is very tightly regulated by the Federal Aviation Administration (FAA). For instance, outside of Restricted Airspace, the flight team must obtain a Certificate of Authorization (COA) from the FAA for UAV operation in US national airspace. The criteria to be used by Department of Defense UAV proponents are contained in FAA Order 7610.4, Special Military Operations, Ch. 12, Sect. 9. This Order suggests that DoD proponents submit an "Application for COA" to the appropriate FAA

Region's Air Traffic Division (ATD) at least 60 days prior to the beginning date of the planned UAV flight operation. The application must include:

(1) a detailed description of the proposed UAV operation, including the classes of airspace required

(2) the UAV's physical characteristics and operational capabilities (e.g., cruise speed, climb/descent rate)

(3) method used to control the UAV (remote or autonomous)

(4) method used to avoid other aircraft

(5) coordination and communication procedures

(6) contingency plans

(7) a statement of airworthiness

Upon approval and issuance, the COA may impose additional conditions for flight conduct.

For instance, a Notice to Airmen may need to be broadcast prior to flight in order to warn other pilots in the area of UAV activities. Also, a direct communications link, either telephonic or personal, is typically maintained between the FAA and the UAV mission manager.[21]

An FAA approved COA was required for each period that the UAV was to be operated outside of restricted airspace, additionally, each modification to the airframe or autonomous flight hardware or software required an updated statement of airworthiness to be approved by an FAA examiner. The coupled lead times for the approved statement of airworthiness and COA were projected to exceed 18 months for each experimental flight.

Facing these two complicating factors, a remotely operated airframe was pursued as a platform for both a wireless mesh extension platform, and a platform which could support an autonomous flight package.

[21] UAV Collaborative, <http://www.uav-applications.org/services/airspace.html>, (29 April 2006).

## B. AIRFRAME

The Mikado Logo 24 airframe was constructed and tested, and a detailed log of the time, materials, skill used, and any outside skill utilized was recorded (See Appendix H). These line items were then analyzed to gain insight into potential systematic points of interdiction. The construction processes followed were those provided by the manufacturer of the airframe kit (See

Figure 12 Mikado Logo 24 RC Helicopter in Flight, Mai Ngat Thailand.

## C. PAYLOAD

The WiFi access point selected was a MeshDynamics 4000 series Access Point (See 0). Because the protective housing surrounding the very light circuit boards weighed 1005 grams (See Figure 13), the board was removed and placed within a plastic enclosure (See Figure 14) this reduced the payload weight by 975 grams.


Figure 13 MeshDynamics 4000 Series Access Point (From: Lounsbury).

Figure 14 MeshDynamics 4000 Series Access Point in Plastic Housing.

The removal of the circuit board from the protective housing exposed the payload to potential shock and environmental hazards. The environmental hazards were mitigated by not flying the airframe when visible moisture was present in the JOA. This procedure also mitigated damage to the airframe as it was not designed to be flown in adverse weather.

## D. BATTERIES

Several different power sources are required to operate the RC helicopter and payload. These batteries were selected to maximize power density and minimize weight. The heaviest and most powerful drove the BLDC motor.

The helicopter main propulsion unit requires two 14.4v LiPo Batteries (See Figure 15)  to drive the main and tail rotors.  Total weight was 756 g.

Figure 15   14.8v 4200 mAh LiPo Battery Pack (From: www.thunderpower.com).

The receiver requires a 4.8v NiMH or NiCd battery pack to power itself, the 4 servos and the heading Gyro; weight 100 g.


Figure 16   4.8v NiCd Receiver Battery (From: www.futaba.com).

## E. ANTENNAS

Due to the continuously varying aspect between the surrogate UAV and linking client on the ground, it was important to select antennas with multi polar $360^{O}$ RF coverage.  Three antennas were needed for the MD4325 WAP, one for the uplink, one for the backhaul, and one for the client antennas.  Because of the triplicate redundancy, it was vital that a light weight antenna with these characteristics be identified.

The antenna that was decided upon was a 3dB Multi polar Omni directional antenna from Wifi-Plus.  The MP-BULLET 2.4/5.x (See MP-BULLET 2.4/5.x Multi Polar Omni Directional Antenna) provides $360^{o}$ vertical and

horizontal coverage and weighs only 100g. These antennas were installed directly to the plastic housing containing the WAP.

Figure 17 MP-BULLET 2.4/5.x Multi Polar Omni Directional Antenna.

## F. AUTONOMOUS FLIGHT PACKAGE

As discussed in paragraph A. above, an autonomous flight package was not implemented into this airframe, however, a flight package was selected to evaluate the both the impacts of the build process and the capacity of the airframe to support the additional weight. The package selected for investigation was the Crossbow MNAV 100CA.

Figure 18 MNAV100CA Navigation and Servo Control Board (From: Crossbow).

The MNAV100CA is a calibrated digital sensor and servo control system designed for use in Radio Control (R/C) vehicles. The onboard sensor package includes accelerometers, angular rate sensors, and magnetometers for use in inner loop control applications as well as static pressure (altitude) and dynamic pressure (airspeed) sensors for use in airborne robotics. A GPS sensor is also included for both path planning and navigation.

The MNAV100CA's comprehensive onboard servo control solution includes both R/C servo control hardware and an R/C receiver Pulse Position Modulation (PPM) interface. R/C servo hardware provides users with software based control of up to nine separate servos while the PPM interface enables software interpretation of R/C receiver commands thereby offering users both automated software control as well as manual "takeover" capability.

Output data are provided in a digital (RS-232) format. Each MNAV100CA system comes with a GPS antenna, interface cables and User's Manual Crossbow's MICRO-VIEW software is also included to assist users with sensor calibration, servo control, data collection and overall system development.

When connected to Crossbow's Stargate Processor Board (SPB400) (See Figure 19), via the standard 51-pin connector, the MNAV100CA combines with the SPB400 to form a sophisticated open-source robotics platform. This comprehensive robotics solution offers users a flexible development platform for state estimation, WiFi telemetry command uplink/downlink and closed loop navigation and control. Payload sensors (e.g., USB image sensor) can also be connected and processed by the Stargate to support intelligent robotics applications.[22]

[22] UAV Collaborative, <http://www.uav-applications.org/services/airspace.html>, (29 April 2006).

Figure 19 MNAV integrated with Complete Robotics Hardware (From: Crossbow),

This autonomous flight system integration was evaluated and entered into the work log with estimations of time, materials, skill used, and any outside skill utilized to help determine the systematic development of an AIED.

# V. EXPERIMENTATION METHODOLOGY

## A. 802.11 TESTING

In evaluating hardware adhering to the 802.11 IEEE standard, it is essential that a formal well defined testing procedure be identified and adhered to for the duration of the test. While COASTS 2005 utilized a specific testing technique, its observations yielded mostly qualitative categorical results which presented analytical difficulties. The COASTS 2006 experiment endeavored to carryout its testing plan in a purely quantitative manner. This change of practice presented a dilemma; develop a testing method from the ground up or utilize a well established testing regimen.

While developing an in-house testing plan from the ground up was initially attractive, because it offered a great deal of flexibility, it quickly became apparent that utilizing a proven industry standard network evaluation plan would provide a highly cohesive and recognizable data set. This result was encouraged by both COASTS 2006 industry partners, who pointed the research team in this direction, and DoD partners who were already utilizing industry standard test procedures in their own evaluations.

The COASTS 2006 Data Collections team, lead by the author, selected the Atheros® Communications Methodology for Testing Wireless LAN Performance as the model. The following discussion is the background discussion from the Atheros white paper, and the adjusted methodology that COASTS 2006 used to address its testing objectives. The white paper in its entirety can be found in Appendix C.

### 1. Introduction

Whether evaluating the performance of wireless LANs in an informal way or through precise benchmarking procedures, the first step is to understand the factors involved. The ease of setting up and using WLANs makes it easy to overlook many crucial factors and their resulting performance variations. These

performance variations can be extreme, however, and they make a dramatic difference in the cost, security and viability of a wireless network.

## 2. An Overview of Throughput and Coverage Factors

A WLAN generally consists of an access point (AP) that connects to a wired network and remote devices (client) that connect to the access point through wireless (radio) links. Throughput is defined as the speed with which a user can send and receive data between a remote device and the access point. Throughput varies across the WLAN's coverage area. This section profiles the main factors that determine WLAN throughput and coverage.

### *a. 802.11 Protocol*

The IEEE 802.11 standard defines various physical-layer rates for different types of WLANs, such as 1, 2, 5.5 and 11 Mbps for 802.11b and 802.11g. Rates for 802.11a and 802.11g include 6, 9, 12, 18, 24, 36, 48 and 54 Mbps. The user throughput is less than these link rates for several reasons:

- Each packet includes additional data, such as preambles, headers (MAC, IP, TCP, etc.) and checksums.
- When every directed (unicast) packet is received, the receiver transmits a short acknowledge packet back to the sender.
- Transmitters wait for short random times between packets to allow other users to contend for and share the channel. Given these reasons, the theoretical maximum user-level performance for the various 802.11 systems is presented in Table 1.

| | Number of Channels | Modulation | Maximum Link Rate | Maximum TCP Rate | Maximum UDP Rate |
|---|---|---|---|---|---|
| 802.11b | 3 | CCK | 11 Mbps | 5.9 Mbps | 7.1 Mbps |
| 802.11g (with .11b) | 3 | OFDM/CCK | 54 Mbps | 14.4 Mbps | 19.5 Mbps |
| 802.11g (with .11g only Mode) | 3 | OFDM/CCK | 54 Mbps | 24.4 Mbps | 30.5 Mbps |

Table 1 Theoretical Maximum User-Level Performance for the Various 802.11 Systems (From: Antheros).

Table 1 assumes 1500-byte packets, encryption enabled, default 802.11 MAC configurations, zero packet errors, and maximum available channel bandwidth (that is, operating at close range). Note that some 802.11 implementations use tricks such as reducing backoff times between packets to improve throughput performance. Such tricks can result in interoperability problems with other vendors' systems.

Table 1 also shows two rates for 802.11g to account for the lower rates in 802.11b compatibility mode. The throughput of an 802.11g WLAN decreases significantly in 802.11b compatibility mode because every 802.11g (OFDM) packet needs to be preceded by a CTS packet exchange recognizable by legacy 802.11b devices. With no 802.11b devices connected, an 802.11g network can operate in 11g-only mode and should achieve the standard throughput of 802.11a. The current 802.11g draft standard also provides for a slower RTS/CTS header (instead of CTS-only) when in 802.11b compatibility mode, which will further reduce the 14.4 Mbps TCP/IP rate to 11.8 Mbps.

There are therefore two choices with 802.11g networks: High rates comparable with those of 802.11a networks can be achieved, or have 802.11b compatibility. Both cannot occur concurrently. Since the key feature of 802.11g is backward compatibility with 802.11b, throughput tests should be done with an 802.11b client device connected to the access point but otherwise idle. This setup ensures that the 802.11g network is operating in an 802.11b compatible mode.

In the COASTS 2006 experiment, great care was taken to ensure that no .11b clients were associated with the wireless mesh. The MeshDynamics APs were also set to .11g only mode. These precautions ensured that the network operated in .11g only mode thereby enabling the network to take advantage of the higher Link, TCP, and UDP rates listed in Table 1.

### *b. The Radio Environment*

Several issues affect the way the radio signal travels from one device to another:

Radio energy attenuates when it propagates. As radio waves propagate outwards spherically, the energy spreads over an ever-increasing area. In free space, doubling the distance decreases the received power by a factor of 4—the so-called $\frac{1}{r^2}$ behavior. Radio signals also attenuate when they pass near or through objects such as floors, walls, furniture and people. The attenuation increases with the object's conductivity (due to metal or water content, for example). The combination of these two attenuation effects reduces radio signal strength by $\frac{1}{r^3}$ to $\frac{1}{r^4}$, or even $\frac{1}{r^5}$.

Antenna designs affect how much radio-frequency (RF) energy is transmitted or received and where it is directed.

Scattering and multi-path cause fading effects. Signal strength can change rapidly as a function of location because the received signal is the sum of potentially numerous signals scattered from nearby objects. As the transmitter or other objects in the environment move, the scattered signals sometimes add together and sometimes cancel each other. Fading can change significantly over distances of a wavelength or so (12.5cm at 2.4 GHz and 6 cm at 5 GHz). Fading also occurs over time as well as location. Even small changes in the environment (for example, people or other objects moving) can affect the fading pattern. This means that the received signal strength can also change quite quickly over time, even when the receiver and transmitter are fixed.

Scattering and multi-path results in delay spread. The received signal might contain several slightly delayed copies of the transmitted signal, as the scattered signals travel via different physical paths of different lengths.

Other devices occupying the same or nearby channels cause interference. For example, the 2.4 GHz spectrum might be occupied by Bluetooth devices, microwave ovens, and cordless telephones.

### *c. Frequency*

A common misconception is that free-space propagation depends upon frequency, so higher frequencies are assumed to propagate less well than lower frequencies. As a good counter example to this misconception, consider visible light, which is simply an ultra-high frequency electromagnetic wave that propagates perfectly well across large distances.

Alternately, effects such as antenna efficiency, RF component performance, and absorption through and scattering around objects do depend upon frequency.  Here are some of the frequency-dependent effects:

Generally, antennae of the same physical size tend to become more directional (have higher gain in some directions and less in others) as the frequency increases. Advantage: 5 GHz.

Absorption due to propagation through objects tends to increase with frequency. Advantage: 2.4 GHz.

Scattering around objects might have a positive or negative effect on signal strength as a function of frequency, depending upon the relative sizes and locations of the objects. Advantage: Neutral.

Noise and spurs generated by nearby electronics (for example, inside the AP or PC laptop) in addition to co-channel interference, such as Bluetooth devices, cordless phones and microwave ovens, will degrade 2.4 GHz sensitivity more than 5 GHz. Advantage: 5 GHz.

Cable loss increases with frequency, so antenna cables (if present) in the AP or laptop will have more loss at high frequency, unless more expensive cables are used. Advantage: 2.4 GHz.

In more open environments, there will be little difference between 2.4 GHz and 5 GHz propagation. For example, measurements of 2.4 GHz and 5 GHz propagation done by WJ Communications in two indoor environments show little difference between 2.4 GHz and 5 GHz propagation.[23]

Typically, the OFDM modes of 2.4 GHz 802.11g networks will have slightly less coverage than 2.4 GHz 802.11b networks. Depending upon the propagation environment, the coverage of 5 GHz 802.11a networks might be similar to, or in some cases less than, that of 802.11g networks. The differences between 2.4 and 5 GHz propagation are generally insignificant compared to the differences between one vendor's equipment and another's, however. An 802.11a product from one vendor might have better coverage than an 802.11g product from another vendor.

#### *d. Fresnel Zone*

The concept of a Fresnel zone may be used to analyze interference by obstacles near the path of a radio beam. The first zone must be kept largely free from obstructions to avoid interfering with the radio reception. However, some obstruction of the Fresnel zones can often be tolerated, as a rule of thumb the maximum obstruction allowable is 40%, but the recommended obstruction is 20% or less.[24] This concept is depicted in Figure 20 below.

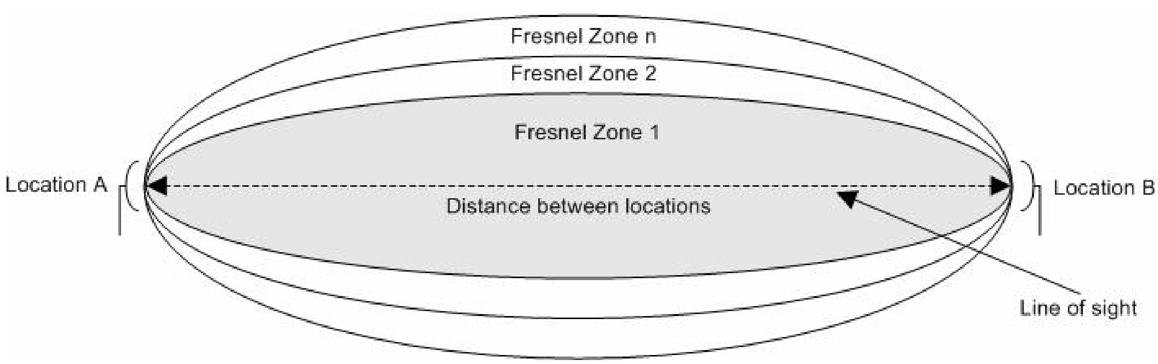


Figure 20 Fresnel Zone (From: www.uninett.no).

[23] WJ Communications, Inc., <http://www.watkins-johnson.com/pdf/techpubs/Indoor_prop_and_80211.pdf>, (3 January 2006).

[24] Wikipedia, Fresnel zone, http://en.wikipedia.org/wiki/Fresnel_zone, (11 May 2006).

In the COASTS 2006 experiment, care was taken to ensure that the individual nodes were kept above the fist Fresnel zone to prevent signal obstruction between the nodes being evaluated.

For establishing Fresnel zones, the RF Line of Sight (RF LoS) must first be determined, which in simple terms is a straight line between the transmitting and receiving antennas. The height of the first Fresnel zone can be calculated by utilizing the following equation.

$$r = 72.05\sqrt{\frac{D}{4f}}$$

$r =$ radius (ft)

$D =$ Distance from antenna (mi)

$f =$ frequency in GHz

Figure 21 Fresnel Zone Radius Equation (From: www.uninett.no).

Initial tests determined that node to node spacing limits were approximately 1.0 mi apart. Substituting 0.5 miles for D (1/2 the distance between nodes) and 2.4 for f into Figure 21 above yields 16.4 feet (See Figure 22). The antenna node heights of 16 ft (See Figure 23) were selected to place the antenna well above the 80% RF LoS zone.

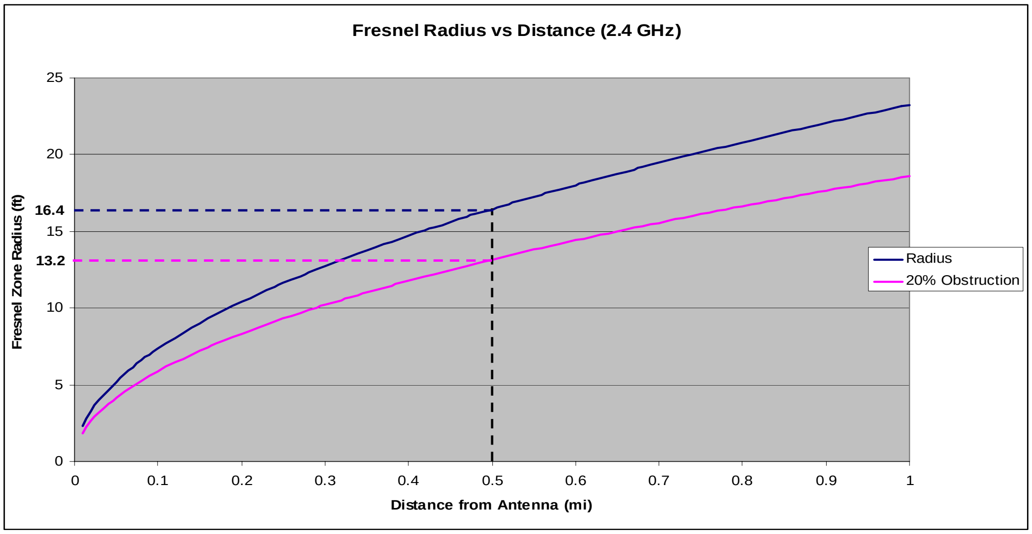


Figure 22 Fresnel Radius vs Distance (2.4 GHz).

Figure 23 Root Node Placement Above the First Fresnel Zone. (From: Russo).

#### *e. Vendor Interoperability*

Products that undergo Wi-Fi certification are certified to interoperate with a wide variety of vendors' products. However, these tests mainly verify basic connectivity and do not enforce stringent throughput requirements. A client device may be able to be connected to a different vendor's access point, but high throughput may not be experienced. Products that provide good performance (throughput, coverage, etc.) when connected to a variety of different vendor's devices are clearly more desirable.

#### *f. Security*

Security includes encryption and authentication. Encryption protects WLAN traffic from eavesdropping and other attacks such as replay or man-in-the-middle attacks. Authentication validates the users' credentials

(ensuring that the user is who they say they are) and also possibly validates the network's credentials (ensuring that the network is what it says it is, and not someone masquerading as the network).

WLAN security standards have progressed from WEP to TKIP and WPA and now to AES (the Advanced Encryption Standard), with significant security enhancements at each stage. No matter what security standard is involved, the way the standard is implemented can affect the WLAN's performance. Specifically, some vendors implement encryption in software, which can dramatically reduce throughput compared to advertised rates. When evaluating performance, it is vital to measure throughput with encryption enabled.

### 3. Measuring Throughput and Coverage

The throughput of WLANs depends heavily on the environment, including the distance between the client and the access point. The throughput generally falls off as distance increases, but factors such as obstructions (like furniture, people, or walls of different construction) also have a significant effect. Throughput does not depend upon distance alone. It is possible to have distant test locations that produce higher data rates than closer locations. Moreover, the peak data rate measured at short distances is not the most important factor in the user's experience. Rather, the rate the user experiences at a variety of distances and locations is a very important factor. Therefore, it is critical to measure WLAN throughput at a variety of locations, including some far from the access point.

WLAN environments generally fall into three categories:

Outdoor: typically a direct line of sight between the access point and client. Examples include outdoor campus coverage, public areas, or even inside large, open buildings such as airport concourses or convention halls.

Open office: no longer a direct line of sight between the access point and client, but typically at most two-to-three obstructions such as walls. Examples are warehouses or offices containing cubicles, lobbies and meeting areas.

Closed office: no direct line of sight, with many obstructions between the access point and the client. Examples are buildings with regular offices and many walls.

Each iterative test sequence in the COASTS 2006 experiment was performed in an outdoor environment. Atmospheric conditions were observed and recorded in an attempt to model the effects of varying atmospheric conditions on 802.11 network performance.[25]

WLAN coverage differs significantly in these different environments. Outdoor WLANs provide the longest ranges and closed-office WLANs the shortest. Different construction techniques also have a significant impact on coverage and throughput. For instance, concrete walls attenuate signals more than stud walls with sheet rock. In general, the relative performance and throughput for different products under test should be similar across the different environments. So if Vendor #1's product is significantly better than Vendor #2's in an open-office environment, it is highly likely (although not guaranteed) that it will be significantly better in other environments. It is possible (although more time consuming) to test products across several different environments to accurately determine the relative performance.

IxChariot from Ixia was used to measure the throughput the user will experience. Typically IxChariot is used to measure TCP throughput in megabits per second (Mbps) in either the uplink direction (for example, upload from the client to the AP) or downlink direction (for example, download from the AP to the client). Downlink TCP performance is the most relevant metric, since it reflects the most common usage such as browsing the web or downloading email.

In the case of the COASTS 2006 meshed wireless networks, backhaul channel throughput was tested exclusively.

[25] Miller, 2006.

### 4. Test Setup

The first step was to decide which antenna configurations and which range would be used. The natural test configuration was to iterate antennas through a pre-designed range of distances.  These distances were spaced .2 mi apart out to 1.6 miles in an array of eight sub-tests.

An example of antenna range testing:

Test 1: Antenna 1 at ranges 1 - 8.

Test 2: Antenna 2 at ranges 1 - 8.

Test 3: Antenna 3 at ranges 1 - 8.

Test 4: Antenna 4 at ranges 1 - 8.

Test 5: Antenna 5 at ranges 1 - 8.

Test 6: Antenna 6 at ranges 1 - 8.

This test procedure was carried out 6 times for each antenna configuration to ensure that an adequate sample size was achieved.

Select a channel for testing, and verify that the RF environment on the selected channel is clear. Use a sniffer or client device to check that there are no access points or ad-hoc networks located on the same channel throughout the test area. For 11b and 11g, this means no overlapping channel; channels with number spacing of 4 or less overlap and cause significant in-band interference. For example, 2.4 GHz channel 1 overlaps with channels 2, 3, 4, 5, and channel 6 overlaps with channels 2, 3, 4, 5, 7, 8, 9 and 10. For 11a the standard 54 Mbps channels do not overlap.

Select at least eight test locations at a variety of locations and distances from the access point (see Figure 24). At least one test location should be at the limit of coverage. (If later it is discovered that one product under test has much

better coverage than initially expected, then additional, more remote, test locations need to be added and the earlier tests with the other equipment to be repeated at these new locations.)

All wireless LANs have a limit on signals that are too strong. Some WLAN products may actually produce low data rates at very close ranges (for example, less than three feet). Therefore, the closest test points should be no less than five feet apart.

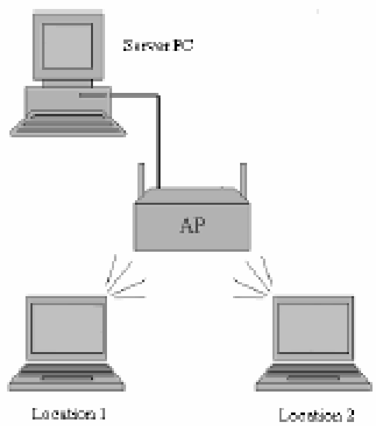


Figure 24 Typical Range and Throughput Setup (From: Antheros).

The key criterion is repeatability. For each product under test, the access point locations, software setup, channel used, overall environment, test procedure and test locations were as close to the same as possible. Environmental repeatability was desired within a test, however variability of the test environmental conditions was welcome as a portion of the COASTS 2006 experiment was investigating the potential correlation of atmospheric conditions and network performance.

At each location, a minimum of six measurements were made to attempt to capture the statistical variability inherent in RF propagation, and IP packet transmission.

### 5. Test Procedure

Putting all the previous steps together, the overall test procedure is:

Setup test #1: Install the desired antenna on the mobile node.

Go to the first test location and conduct a throughput test on IxChariot.

For each location, record the time and distance of the mobile node from the root node in the IxChariot log file as it is saved to the appropriate test folder which is labeled with the antenna being tested.

Repeat steps 1-3 for each test location.

Repeat steps 1-4 for each antenna configuration six times.

This is a natural point at which to discus the software package that was used to gather the performance of the throughput tests and log the results.

### 6. Mesh Dynamics Network Mesh Viewer

Another useful tool used for network situational awareness was the Mesh Dynamics Network Mesh Viewer (NMV). Through the network interface, Mesh Viewer would analyze the network; gather information on all access points that were active and passing data, and report wireless signal strength in dBm, internal board temperatures in Celsius, and throughput in mega-bytes per second (Mbps).

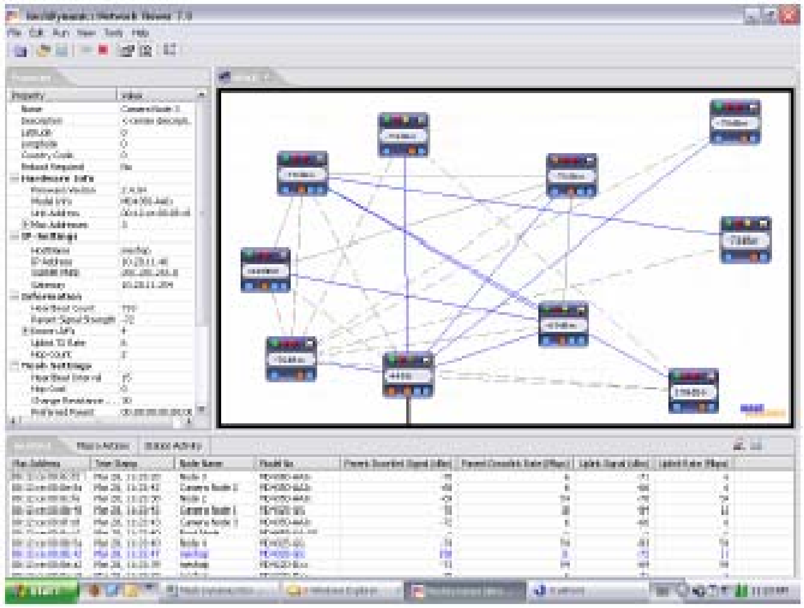

Figure 25 Mesh Viewer Screen Shot (From: Lounsbury).

## B. ENVIRONMENTAL MONITORING

In an effort to document the possible effects of atmospheric conditions on the performance of each of the technologies included in the COASTS 2006 experiment, it was deemed necessary to select a weather monitoring solution which was weather proof, ultra portable, capable of logging a full day's worth of data, and require very little power. This array of desired attributes was found in a COTS solution from Kestrel Meters®.

### 1. Kestrel Handheld Weather Station

The Kestrel 4000 Handheld Weather Station (see Figure 26 was the primary source for data collection for COASTS 2006. Each of the discreet data points collected included the following observations:

- Wind Speed
- Wind Chill
- Air Temperature
- Dew Point

- Barometric Pressure
- Wet Bulb Temperature
- Heat Index
- Altitude
- Density Altitude
- Time of Collection Point


Figure 26 Kestrel 4000 Hand held Weather Station (From: www.kestrelmeters.com).

The Kestrel is capable of storing 2000 summary data points (See Appendix D for complete list of specifications), with an onboard configurable collection interval between 2 seconds and 12 hours. This internal storage capacity offered the experiment a very detailed view of the subtle atmospheric fluctuations experienced in each of the environments where testing was undertaken.

The Kestrels were placed in three different locations at each experimentation location. A unit was mounted to the root node, another was mounted to a balloon payload and hoisted to 2500' Above Ground Level (AGL) and the third was carried with the testing team to each endpoint testing location.

Another valuable attribute of the Kestrel Meter system was its ability, when docked in a base station, to provide a World Wide Web (WWW) servable webpage (see Figure 27) which provided real time observation and at-a-glance atmospheric trends. This added feature provided valuable real time feedback and a greater situational awareness to the NOC team as they were conducting and supervising testing and scenario operations.


Figure 27 Kestrel Weather Station Graphical Interface (From: Miller)

Each day that experimentation was to take place, each weather station was calibrated in accordance with Appendix E, and at the day's end upon conclusion of testing, a member of the Data Collections team retrieved each station and downloaded the stored data to comma delimited files for incorporation into the COASTS 2006 observation data base for follow on analysis.

# VI. EXPERIMENTATION AND RESULTS

## A. 802.11 MESHED NETWORK

As discussed in Chapter V, the IX Chariot evaluation software requires an endpoint client to conduct testing. For each iteration of the COASTS 2006 field experimentation program, a Windows XP configured laptop served as the hardware upon which this endpoint software was run. Ixia supplies several specific endpoints specifically designed to be installed on WAP for the very reason that it is impractical for each node of a network to require a dedicated hardware platform to serve as the endpoint client. Ixia and MechDynamics have developed a client specifically designed to operate on the MD4000 family of WAP; however, the necessary client was not available in time to be utilized in this experiment. Because of this, the evaluation of the WAP on the UAV surrogate in flight was not possible given the payload restrictions inherent to the airframe.

Given the payload weight restriction, and the anecdotal documentation that the RF energy produced by an RC Helicopter falls into the spectrum below 300 MHz,[26] well below the 2.4GHz frequency that the MD4000 WAP operates on, WAP testing was conducted on the ground as part of the COASTS 2006 experiment. This effort was considered valid as in each case the root and remote client access points were each raised to a height greater than that of the first Fresnel zone radius above the ground. This antenna height ensured that a minimal amount of RF loss occurred and closely simulated an airborne access point with regard to Fresnel zone propagation concerns.

With this construct in mind the following results were achieved utilizing the testing methodology discussed in Chapter V.

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[26] About Spektrum DSM Digital Spectrum Modulation. Provides unequalled RC signal resolution, and is immune to the most common forms of RF interference. <http://www.modelflight.com.au/spektrum_whyisitbetter.htm>, (9 March 2006).

### 1. Throughput vs. Distance Testing

One thousand five hundred twenty data points were analyzed utilizing a binning technique with bin sizes of 10 observations each. This resulted in 152 discrete data points which follow a normal distribution (Figure 28).

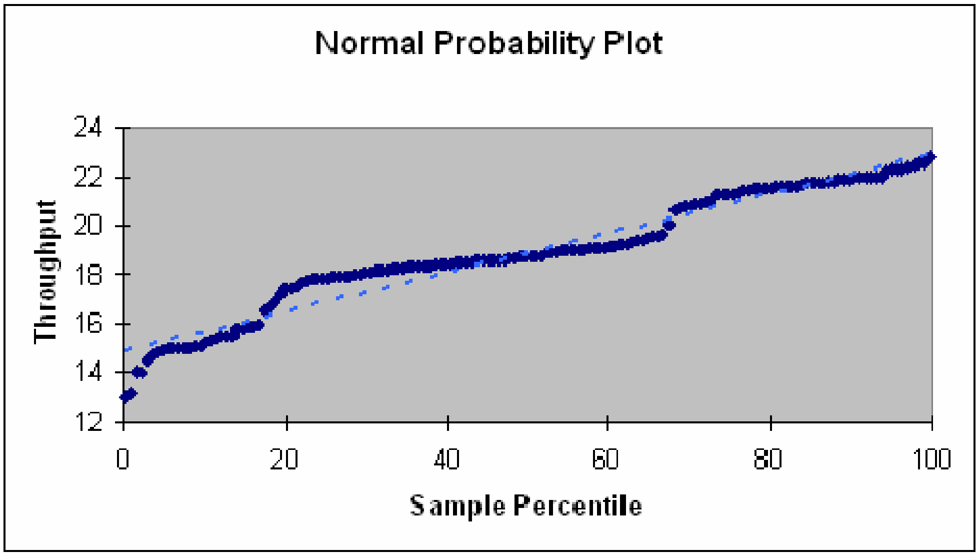


Figure 28 Normal Probability Plot (Throughput).

Linear regression analysis was then performed to fit the following linear model:

$$\hat{Y} = 21.906 - 6.253x \qquad \text{Eqn. 1.1}$$

Where, in Eqn. 1.1, $\hat{Y}$ represents the fitted throughput value and **x** is the dependant variable Range. This yielded a randomly scattered plot of residuals signifying homoscedastic variability.

This yielded a well fit linear model demonstrated by the t statistic and p-value shown in Table 2.

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* |
|---|---|---|---|---|
| Intercept | 22.12376193 | 0.296382885 | 74.64588212 | 1.6202E-120 |
| Range.miles. | -6.781182591 | 0.553867046 | -12.24334007 | 2.48097E-24 |

Table 2 Linear Model and Model Statistics.

A plot of the fitted linear model and the associated upper and lower 95% prediction curves (Figure 29) identify both the linearity and high variability of dependant variable (throughput) across the range of tested distances.

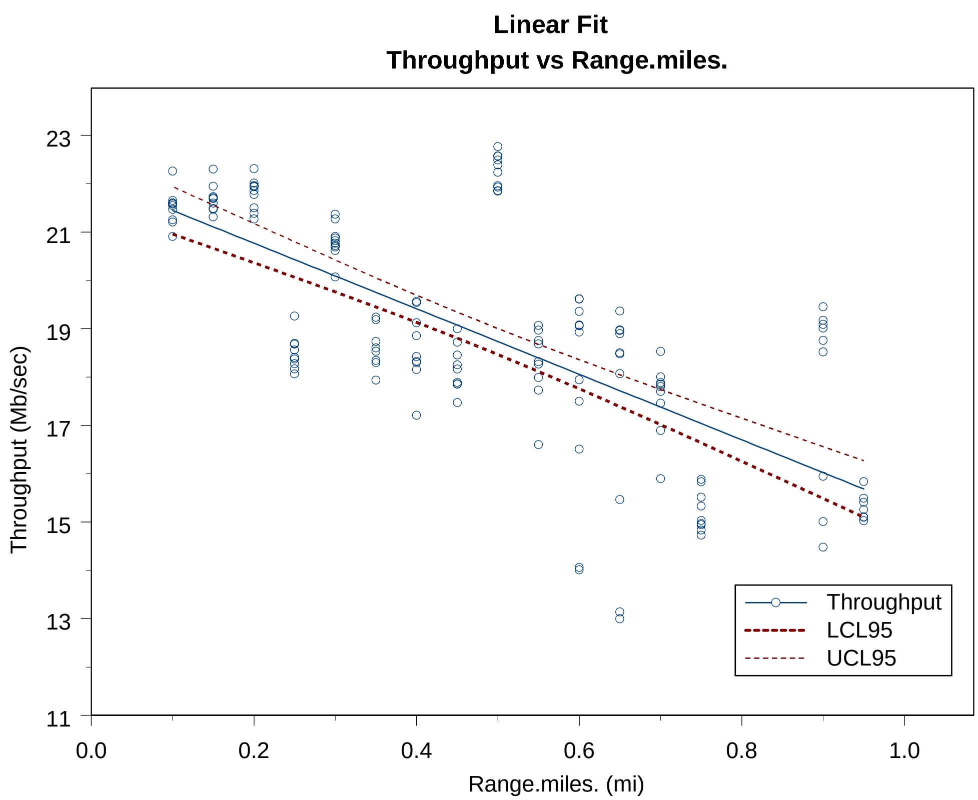


Figure 29 Plot of Linear Fit (Throughput vs. Range.miles.)

The overall variability of is only partially explained in the linear model by the influence of range. This can be readily identified by the Multiple R Squared value in Table 3.

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.706988145 |
| R Square | 0.499832237 |
| Adjusted R Square | 0.496497785 |
| Standard Error | 1.674010732 |
| Observations | 152 |

Table 3 Regression Statistics

The 30% of variance which is unaccounted for may well be explained by the introduction of error through the testing process or by subtle variations in atmospherics.[27] Radio wave propagation theory states that energy received from a radiating source is at least indirectly proportionate to the distance away from the source. The linear model suggests, as would be expected, that information sent along a radiated frequency is also indirectly proportionate to the distance between two meshed nodes of a network.

However, the identified WAN MOP for the purposes of this experiment was a 10 MB through put out to 1 mi. To test whether this MOP was achieved, a simple hypothesis test was performed on the same set of binned data.

$$n = 152$$

$$\alpha = .05$$

$$\bar{x} = 18.89$$

$$\sigma = 2.359161$$

$$H_0 \leq 10$$

$$H_a > 10$$

$$\mu_x = \mu = 18.89$$

$$\sigma_x = \frac{\sigma}{\sqrt{n}} = \frac{2.35}{\sqrt{152}} = .191$$

$$Z = \frac{\bar{x} - \mu_x}{\frac{\sigma}{\sqrt{n}}} = \frac{18.89 - 10}{.191} = 46.63$$

$Z_{.05} = 1.64$ From normal table.

Z>1.64 so we must reject $H_o$ and conclude that Throughput is >10 Mb/sec.

[27] Miller, 2006.

## B. VTOL UAV SURROGATE

### 1. Construction

The VTOL UAV surrogate was constructed in accordance with the manufacturer's specifications included in Appendix F. The construction process was documented and observed for any key skills or tools which might be needed to complete the project. The following table is a summary of results obtained from Appendix H.

| Step | Description | Time (min) | Tech Assist Time | Special Tool Time |
|---|---|---|---|---|
| 1 | Main Frame | 898 | 0 | 152 |
| 2 | Motor Installation | 273 | 60 | 0 |
| 3 | Tail Rotor | 231 | 0 | 0 |
| 4 | Tail | 420 | 84 | 84 |
| 5 | Main Rotor Head | 519 | 47 | 47 |
| 6 | Avionics, Wiring and Power Installation | 499 | 303 | 136 |
| 7 | RC Programming | 243 | 243 | 136 |
| 8 | Axis Trims | 402 | 369 | 0 |
| 9 | Flight Testing | 262 | 260 | 260 |
| | Total | 3747 | 1366 | 815 |

Table 4 Construction Build Times (min.).

Table 4 indicates 36% of the build time required technical assistance out side of basic mechanical skills and that 22% of the time specialized tools were required. All of these specialized skills and tools are common to the RC helicopter enthusiast and would generally require a single experienced source for construction and operational testing of an AIED.

### 2. Flight Training

The ground up development of a UAV requires testing and development in a remotely controlled platform prior to the implementation of an autonomous flight package. Without the ability to remotely pilot the airframe, flight excursions common to autonomous flight package implementation would not only be monetarily prohibitive but would also greatly increase the development phase of implementation. In an environment where supply of technology related materials

may be limited, multiple losses of airframes would be intolerable. This need to control the aircraft in critical phases of flight during development is essential. With this fundamental assumption explained, RC helicopter flight training was undertaken.

At the end of the process, over 75 simulated flight hours were logged and over 140 flight hours. This process spanned five months and required numerous parts replacements which included main blades, tail rotor drive belts and main transmission gears. By the end of the process of training the airframe remained intact but the main servos and brushless DC motor were showing signs of service life wear. This was evidenced by a somewhat sluggish control response and a lack of power margin. All this considered, the time to replace all these parts given a ready supply was accomplished in the span of an afternoon and operationally tested and adjusted within an hour.

# VII. CONCLUSIONS AND FUTURE RESEARCH

## A. CONCLUSIONS

### 1. Extension of Wireless Network Utilizing a VTOL Platform

Given the equipment tested it has been shown that the mesh dynamics WAP provides a 10 MB/sec networking solution which can be implemented on a mini VTOL UAV platform. This platform can be used to extend wireless communications as well as provide a control link for associated autonomous flight packages utilizing TCP/IP protocols.

### 2. AIED Systematic Identification

Initial literature review signified that contemporary frequency spaces utilized by RC aircraft fall into a readily identifiable range of 27, 72, 75 MHz, and 2.4 GHz. The highest range being the most cluttered space and there for most readily masked. A heightened use of these frequencies during daylight hours would be an might be an indication of RC training.

Without an autonomous flight package, flight of an AIED would be restricted to line of sight operation of no more than .25 miles. For a credible threat to be achieved an autonomous flight equipped airframe would be essential. As such, the purchase of small autonomous flight hardware packages such as those in Figure 19 are essential for the successful deployment of a non line of sight AIED. This being the case, the monitoring and tracking of such devices would aid in the identification and possible production process of an AIED.

Also identified as a critical contributing factor in AIED production, are experienced RC pilots with the knowledge and ability to test an airframe throughout the development process. Throughout the United States and in other countries, these individuals are, for the most part, self identifying through club memberships, presence on the internet, and through regional “Fly-ins.”

## B. FUTURE RESEARCH

While engaged in the COASTS 2006 project, it became readily apparent that a possibility might exist for interference between the frequencies generated by the rotating bodies and controls of an RC helo and the communication devices in the program. With that in mind future research should be conducted in the analysis of RC helo RF interference with 2.4 GHz and 5.8 GHz spectrum, to include identification of optimal Main rotor speed / MR blade length to minimize RF interference.

From the beginning of the project it was apparent that helicopter flight is very in efficient both in power consumption and survivability should a flight control excursion occur. With that in mind a comparative analysis of power requirements between mini-fixed wing UAV and mini-rotary wing UAV platforms given a specific payload configuration is highly recommended, the aim of which would be developing targeted implementation appropriate to each platform.

Also, apparent after flight testing was the potential for logistic difficulties associated with UAV operations in a remote environment. Given that potential difficulty a logistics analysis of Mini-UAV platforms to include crash survivability and in field maintenance requirements might produce valuable insight into the mid to long term implementation of UAV's in the field.

# APPENDIX A. COASTS CONOP 2006 (01-04-06)


## Coalition Operating Area Surveillance and Targeting System (COASTS) Thailand Field Experiment (May 2006) Concept of Operations

**NAVAL POSTGRADUATE SCHOOL**

**MONTEREY, CALIFORNIA**

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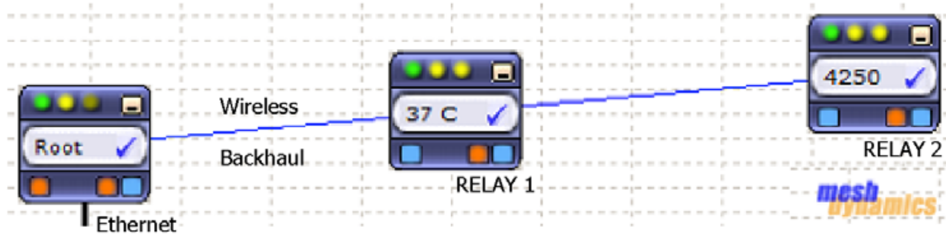
# APPENDIX B. MD4000_HWMANUAL

## Hardware Installation and Maintenance

## MD4000 Product Family

## Terminology




**Root and Relay Nodes**
Mesh Networks provide long range connectivity by relaying packets from one mesh node to another, like a bucket brigade. The end of the bucket brigade terminates at the root – which connects to the Ethernet. (above) Relays connect to the root or other relay nodes to form a wirelessly linked chain.

**Upstream & Downstream**
Upstream implies closer to the Ethernet. The root is upstream of relay 1.

**Wireless Uplinks and Downlinks.** The Ethernet link is the uplink (upstream link) connection for the root. The root has is a wired uplink. Its "backhaul" is the wired network.

Relays have wireless uplinks through a upstream downlink radio. Downlink radios act like Access Points (AP) : they send out a beacon. Uplink radios act like clients – they do not send out a beacon.

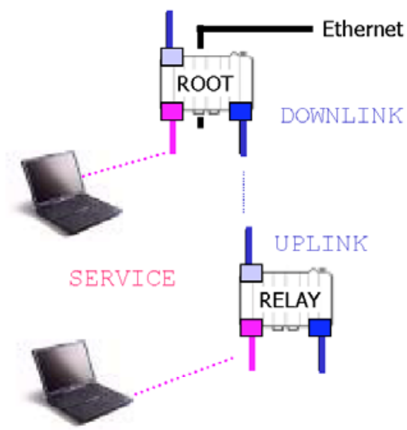
A wireless radio card in the laptop can inform you of the presence of downlinks but not of uplinks. Downlinks beacon, Uplinks do not.

The uplink and downlink radios form a wireless backhaul path.

**AP radios** operate in the 2.4GHZ band to service 11b/g clients. 802.11a wireless devices may be serviced by the 5.8G downlink.

Thus, both 802.11a and 802.11b/g client access is supported.

Backhaul radios operate in 5.8GHZ band to avoid interference with the 11b/g 2.4GHZ AP radio (shown pink, right).




**To summarize,** there are 4 types of "links" to Structured Mesh™ products:

- A wired uplink to provide Ethernet connectivity. This connects the Root node to the wired network.
- A wireless downlink to provide wireless connectivity. Acts like an AP for the uplink. Typically 5.8G.
- A wireless uplink to connect to upstream mesh nodes. This is a "client" to the downlink. Typically 5.8G.
- A AP radio for clients. Typically 2.4G with support for both b and g clients.

In our standard offering, the 11a uplink, the 11a downlink and 11b/g service are 3 separate radios (Fig 2.2).

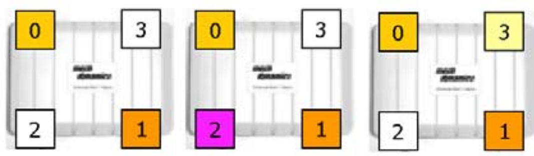
The MD4000 Modular MeshTM products support up to 4 radios in a single enclosure. Slots 0, 1 house one uplink and one downlink radio operating on non-interfering channels but in the same frequency band. They are both 2.4G or both 5.8G. radios.

Note: This two radio backhaul differs from competing mesh products. The differences are explained at: www.meshdynamics.com/WhyStructuredMesh.html

Slot 2 houses a 2.4G AP radio for client connectivity. 2.4G radios can be set to b. b and g or g only modes. Slot 3 can house a 2nd downlink, 2nd AP or a scanning radio for mobile mesh module - that form part of the meshed backhaul in dynamic infrastructure mesh networks.

The 2 Ethernet ports on each module may be used to interface to cameras for high resolution video over mesh. A 2nd (slave) module attaches via Ethernet to provide a total of 8 radios. Operating temperature range is -40 to +85 Celsius. The die cast weather proof enclosure is NEMA 67 rated.

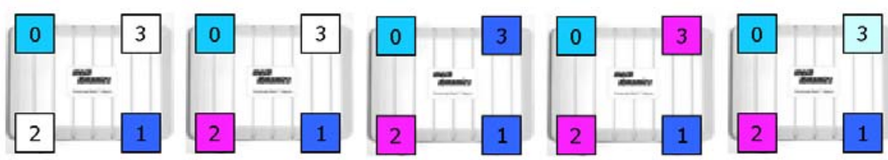
## 2.4G Backhaul Products (Standard Configurations)



MD4220 MD4320 MD4325


1. MD4220-BBxx: 2-Radio module 2.4G uplink and downlink Backhaul (BH). .
2. MD4320-BBBx: 3-Radio module 2.4G sectored BH slots 0,1 and 2.4G AP radio in slot 2.
3. MD4325-BBxB: 3-Radio module 2.4G BH, Downlink also acts as AP. A 2.4G Mobility Scanner in slot 3.

## 5.8G Backhaul Products (Standard Configurations)



MD4250 MD4350 MD445 MD4458 MD4455

1. MD4250-AAxx: 2-Radio module 5.8G BH uplink and downlink Backhaul (BH).
2. MD4350-AABx: 3-Radio module 5.8G BH and 2.4G AP radio in slot 2. AP modes may be b, g, or b & g.
3. MD4452-AABA: 4-Radio module 5.8G BH and 2.4G AP radio. Second sectored 5.8G downlink in slot 3.
4. MD4458-AABB: 4-Radio module 5.8G BH and 2.4G AP radios (two) in slots 2, 3 for sectored service.
5. MD4455-AABA: 4-Radio module 5.8G BH and 2.4G AP radio in slot 2. 5.8G Scanner in slot 3

## Notes:

1. All 2.4G Downlinks and APs may be configured to support b only, g only, or b & g client connectivity
2. All 5.8G Downlinks may be configured to provide 802.11a client connectivity
3. All radios interfaces may be configured to provide IEEE 802.11e differentiated Class of Service

For a "good signal", the fraction of the energy from the transmitter that reaches the receiver should exceed the receiver radio's receive sensitivity. If not, the ACK will not be sent and re-transmission occurs. Throughput then declines. The rate control software on the mesh module is sampling the link quality between its uplink and the parent downlink. If the throughput declines, it lowers the transmit rate, since transmit power and receive sensitivity improve at lower transmit rates. The throughput is thus adjusted based on signal quality.

Degradation of signal quality over distance is expressed by the free space path loss relationship:

```
Path_Loss = 20*log(Freq) + Decay_* 10*log(Dist) - K where
Path_loss: Path Loss in dBm
Freq: Frequency in MHZ
Decay : Varies based on RF environment, line of sight etc.
Dist: Distance between the two mesh nodes (in meters)
K: Constant.
```

Transmit power from the radio and antenna gains offsets this path loss. The adjusted value must then exceed the receiving radio receive sensitivity for transmissions to be "heard". Table A1 shows backhaul distances for a 5.8G radio transmitting with 20 dBm transmit power radio and over two 8 db omni-directional antennas. Acceptable receive sensitivity is set at – 65 dBm. Decay is varied from 2.0 (rural, open space) to 2.4 (more urban settings, non line of sight, occlusions, interference). Notice how range is dramatically affected by changes in Decay.

Table A1

| Case | RS (dBm) | TR (dBm) | Decay | Ant 01 | Ant 02 | Freq (MHZ) | Dst (m) | Dst (Ft) |
|---|---|---|---|---|---|---|---|---|
| 01 | 65 | 20 | 2.0 | 8 | 8 | 5800 | 461 | 1512 |
| 02 | 65 | 20 | 2.2 | 8 | 8 | 5800 | 264 | 866 |
| 03 | 65 | 20 | 2.4 | 8 | 8 | 5800 | 166 | 544 |

Increasing antenna gain from 8 dBm to a 14 dBm panel on the downlink reduces this path loss (Table A2).

Table A2

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 01 | 65 | 20 | 2.0 | 14 | 8 | 5800 | 921 | 3017 |
| 02 | 65 | 20 | 2.2 | 14 | 8 | 5800 | 495 | 1622 |
| 03 | 65 | 20 | 2.4 | 14 | 8 | 5800 | 295 | 967 |

Panels have a less dispersed beam pattern than omni-directional antennas. Their restricted field of view also makes them less sensitive to noise in the vicinity. In very noisy settings, more radio transmit power may be needed. Two downlinks doubles transmit radio power from 20 dBm to 23 dBm. (Table A3).

Table A3

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 01 | 65 | 23 | 2.4 | 14 | 8 | 5800 | 394 | 1290 |

Range is also effectively doubled by changing from 5.8G to a 2.4G backhaul. Compare Table A4 with Table A1.

Table A4

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 01 | 65 | 20 | 2.0 | 8 | 8 | 2400 | 1115 | 3655 |
| 02 | 65 | 20 | 2.2 | 8 | 8 | 2400 | 589 | 1931 |
| 03 | 65 | 20 | 2.4 | 8 | 8 | 2400 | 346 | 1135 |

Unfortunately, the 2.4G RF space is "polluted" with multiple AP and client devices. 2.4G Backhauls are best limited to rural areas with low subscriber density and low 2.4G RF interference. If 2.4G Backhauls are critical, reduce 2.4G RF interference on the backhaul with a panel antenna and its more focused beam. The 4320 3-radio 2.4G backhaul product is intended to be used with panels on the backhaul and an omni for the 3rd 2.4G AP radio .

**Suggestions**

In rural areas or low client density situations, use 2.4G backhauls preferably with panels to reduce RF interference from other 2.4G devices. In all other scenarios use 5.8G Backhauls. Start with two 8 dBm 5.8G omni-directional 250m apart, with clear line of sight and no metal obstructions with 1.5m of the antennas. Increase node spacing till throughput begins to decline – look at the heart beats shown on the NMS. For noisy 5.8G environments, reduce path loss with panels and/or double the transmit power with dual downlinks (4452).

Table B1

| Case | RS (dBm) | TR (dBm) | Decay | Ant 01 | Ant 02 | Freq (MHZ) | Dst (m) | Dst (Ft) |
|---|---|---|---|---|---|---|---|---|
| 01 | 65 | 20 | 2.0 | 8 | 8 | 5800 | 461 | 1512 |
| 02 | 65 | 20 | 2.2 | 8 | 8 | 5800 | 264 | 866 |
| 03 | 65 | 20 | 2.4 | 8 | 8 | 5800 | 166 | 544 |

Table B2

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 01 | 65 | 20 | 2.0 | 8 | 8 | 2400 | 1115 | 3655 |
| 02 | 65 | 20 | 2.2 | 8 | 8 | 2400 | 589 | 1931 |
| 03 | 65 | 20 | 2.4 | 8 | 8 | 2400 | 346 | 1135 |

Table B1 and B2 indicate that the range of the 2.4G radios backhaul will always exceed that of the 5.8G backhaul. The theory does not take into consideration two salient real-world differences between backhauls and AP radios:

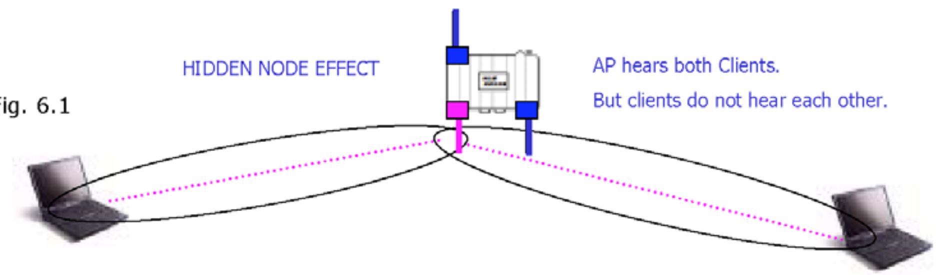
1. Antennas are generally mounted on roof tops. The backhaul antennas generally have free space line of sight connectivity. However the antennas of the AP, also mounted on roof tops, must connect with clients on the ground. The path from AP antennas to the 2.4G client radios is often not clear line of sight. Additionally, there is significant 2.4G RF interference in urban areas. With higher decay the range is significantly reduced (Table B3).

Table B3

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 01 | 65 | 20 | 2.6 | 8 | 8 | 2400 | 221 | 724 |
| 02 | 65 | 20 | 2.8 | 8 | 8 | 2400 | 150 | 492 |
| 03 | 65 | 20 | 3.0 | 8 | 8 | 2400 | 108 | 352 |

2. Clients on the same AP also can also create RF interference due to Hidden-Node effects. The AP has big ears (high receive sensitivity). Even though clients radios are much lower power, the AP can hear them. It also has a loud voice (high transmit power) so clients can hear it. But clients may not be able to hear each other such as when clients are on opposite ends from each other. The clients are thus "hidden".

Fig. 6.1




Radio is a shared medium: only one device should be active at any time. If clients are "hidden" from each other, then they could be talking at the same time, causing RF interference and loss of signal quality. Table B4 indicates that clients hear each other only within 100 meters .In noisy or occluded settings it could be as low as 50 meters.

Table B4

| Case | RS (dBm) | TR (dBm) | Decay | Ant 01 | Ant 02 | Freq (MHZ) | D (m) | D (Ft) |
|---|---|---|---|---|---|---|---|---|
| 01 | 65 | 15 | 2.0 | 0 | 0 | 2400 | 99 | 326 |
| 02 | 65 | 15 | 2.2 | 0 | 0 | 2400 | 65 | 214 |
| 03 | 65 | 15 | 2.4 | 0 | 0 | 2400 | 46 | 151 |

**Suggestions**

If omni-directional antennas are being used, select ones with down tilt. This focuses the beam downwards – where the clients. This also reduces the AP range so clients are less spread apart. The hidden node effect is thus curtailed. For noisy /occluded environments, reduce path loss with panels and/or double transmit power with dual AP radios.

**Note**: Range Calculation Sheet location: www.meshdynamics.com/DOWNLOADS/MDRangeCalculations.xls

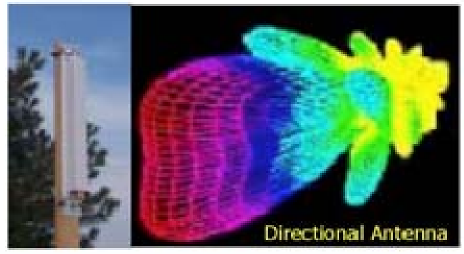




Figure 6.1

Omni-directional antennas provide an even distribution of RF energy (above, left). Directional antennas, in contrast, focus RF energy towards a receiver in their line of sight. Omni-directional antennas as less efficient that directional antennas as distance between the relay increases. In the event the RF signal is weak, over long ranges, Sector or Panel antennas should be considered.

When ordering omni-directional antennas for the up/down links, look at the **down tilt** and **vertical beam width** specifications. If the relays are at different heights,or differing angles then the RF beams may not "connect".

The service radio antenna, if omni-directional, should have a large down tilt, if mesh nodes are mounted up high. In that case the beam has to travel downwards to reach client devices (e.g. laptops) on the ground.

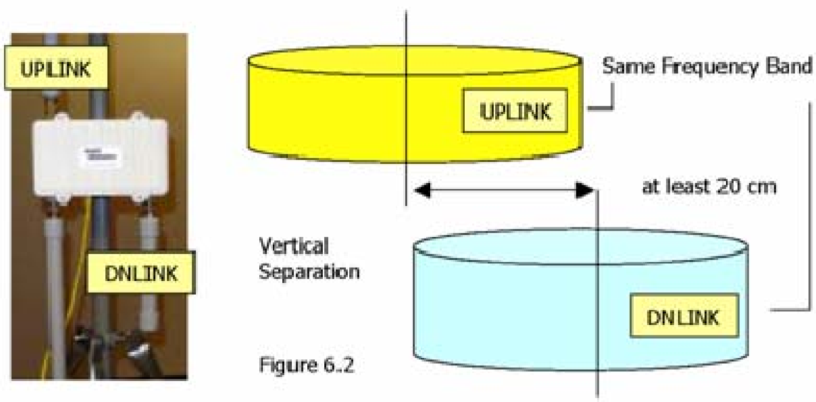



Figure 6.2

The up-link and down-link antennas operate on the same frequency band – they are either BOTH 11a or 11b/g. The mesh software allocates non-interfering channels but it is still good practice to keep the antennas at least 20 cm apart and with vertical separation so the doughnuts" don't overlap.

For all antennas, avoid placements where the open end of is near metal poles or near power transformers. Also omni-directional antennas, should be mounted as vertical as possible and at similar heights for best results. Note at the down tilt and beam width affects permissible height variations, based on the tangent of the angle times the distance.

Understanding the beam pattern of omni-directional antennas and the "vertical window of connectivity" that is available at any given distance is important in the alignment of the antennas for the mesh backhaul, It is especially important when the terrain for the mesh deployment varies in elevation, and/or the objects on which the mesh nodes will be mounted vary in height.

An omni-directional antenna has a radiation pattern that looks like a horizontal disc emanating from the antenna. The disc gradually gets thicker as you move farther from the antenna, and the angle that describes how fast it gets thicker is called the "vertical beam angle".

Given that the antennas are mounted perfectly vertical (please use a level to ensure this), there will be a vertical window at any given distance from a first backhaul antenna within which a second backhaul antenna will be able to receive signals transmitted with the full rated gain of the first antenna.

In the diagram below, the 18 degree vertical beam angle shown corresponds to a preferred 8dBi, 5GHz omni antenna. One can think of this vertical pattern as two right triangles back-to-back where each has a 9 degree angle - one triangle facing up and one facing down relative to a horizontal line.

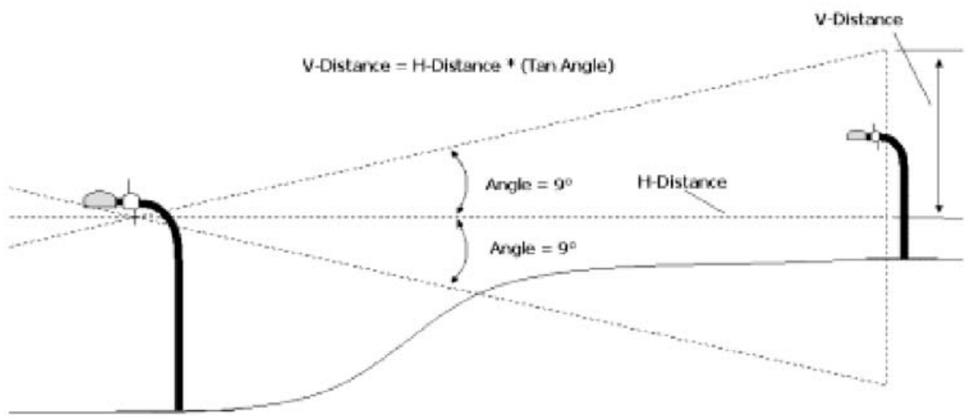



Figure 7.1

Here is how the trigonometry works for omni-directional antennas.

The side of each triangle opposite the 9 deg angle (V-Distance) represents the height above and below horizontal that the antenna's radiation pattern will cover given that you are some distance away, for instance 800 ft. The tangent of 9 degrees is 0.158, so at an 800 ft distance, the pattern will cover a height of (800 * 0.158 =126 feet) above, as well as 126 feet below horizontal for a total vertical window of 252 feet. If however, the antenna on the first node is tilted only 3 degrees from vertical and tilted in the wrong direction relative to a second node, the vertical connection window available at the second node is now reduced to that resulting from a 6 degree angle giving a height of (800 * 0.105 = 84 feet) from horizontal in the direction of interest instead of 126 feet.

As the distance between the mesh nodes grows, the vertical window enlarges. As the distance between mesh nodes is shortened, the vertical window shrinks. For instance, if for some reason the nodes were placed 300 ft apart, the connectivity window would be (300 * 0.158 = 47) feet above and 47 feet below. Basically, the further apart the nodes are, the less sensitive they are to the relative height of the nodes.

## Suggested Check List

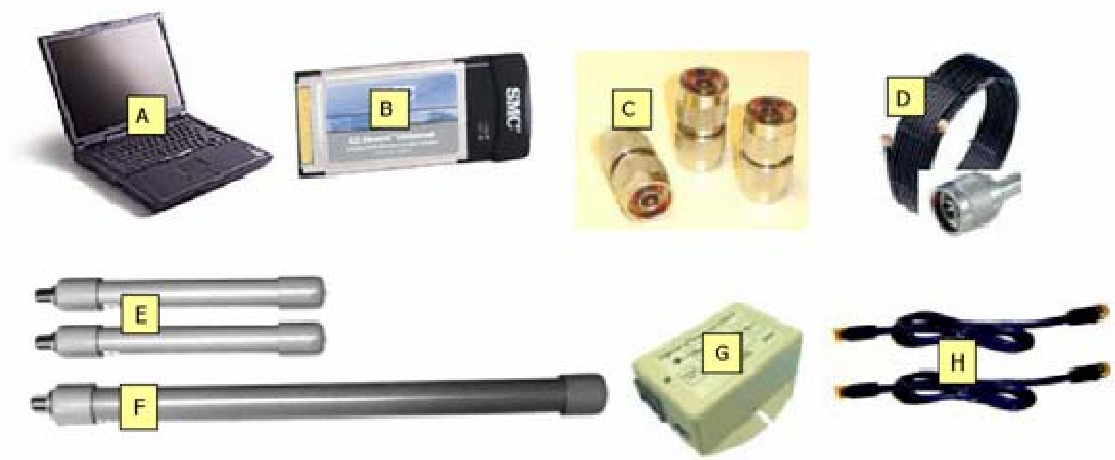



Figure 8.1

A. Windows 98 or better laptop with PCMCIA card and Ethernet Port Access.
Temporarily disable firewalls on the laptop if you intend to configure the nodes with the NMS

B. 802.11 a/b/g card. Model Shown: SMC 2336 W-ACG. Needed for any remote diagnostics.

C. N-Male to N-Male Barrel Adaptors. Needed to temporarily mount Antennas on Structured Mesh™ Module

D. N-Male to N-Male low loss Cabling. Connects Antennas (E, F) to N-Female Connectors on Module

E. Downlink and Uplink Antennas. Two required. For Backhaul. Typically 11a (5.8G), Full range.

| | |
|---|---|
| 5.8Ghz Omni-directional | www.Superpass.com/SPDJ6O.html , www.Superpass.com/SPDJ6OP.html |
| 5.8Ghz Sectored BH | www.Superpass.com/SPPJ19.html |
| 2.4Ghz Sectored BH | www.superpass.com/SPLG22.html |

F. Service Antenna for connecting to client devices (e.g. laptops). Typically 11b/g (2.4G).

2.4Ghz Omni-directional: www.Superpass.com/SPDG16O.html , www.Superpass.com/SPDG16OP.html

G. Power Over Ethernet (POE) injector.

Input Voltage 110V, Output 24VDC on Pins 4,5 of Ethernet RJ45 Connector.
Not included with modules but may be purchased separately from Meshdynamics.

H. RJ45 Ethernet Cables. Two needed. One connects to the wired network, the other to the node.

**Notes:**
1. Items E.F relates to a typical 3-Radio Mesh Module: 11a uplink/downlink and 11b/g service.
If the uplink and downlink or service radio types/settings change, please change antennas accordingly

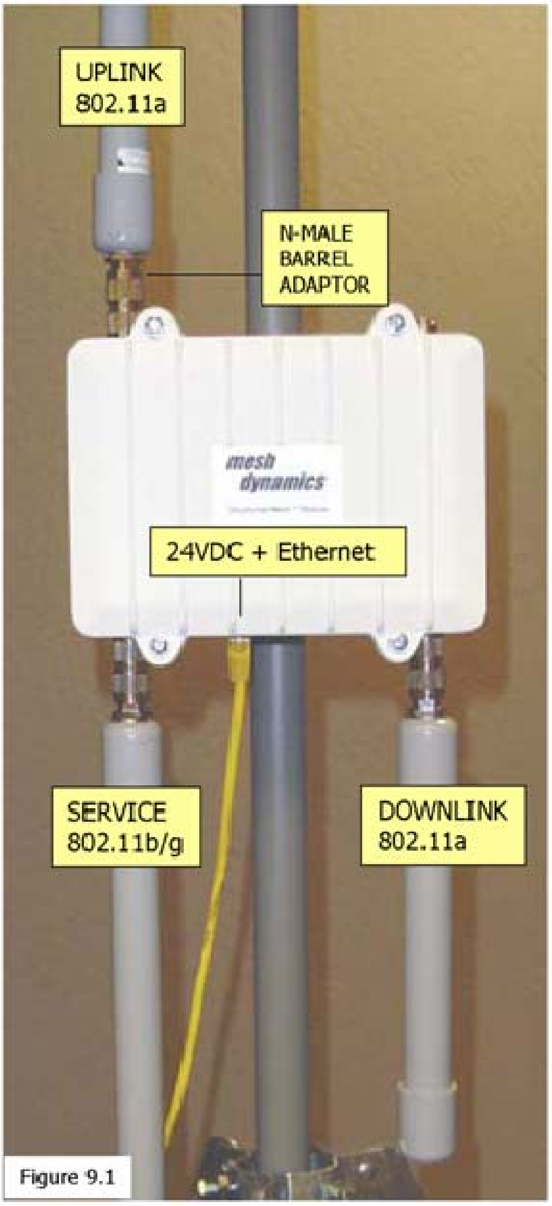


Figure 9.1

*Antenna Mounting Shown for illustration Purposes Only.*

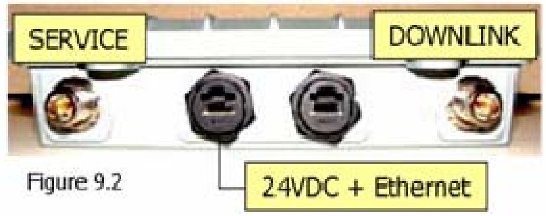


Figure 9.2

**Note**: Units built after August 2005 have connections on the module is shown in Figures 9.1, 9.2


Example: 0805 is the MMYY date of manufacture.

If there is no number on your sticker, then uplink and downlink connections are reversed. But switching them also requires opening the module and placing the radios in different mini-PCI slots, as described later

Switching to the current convention is advised, but does not affect performance of the unit. Reversing the uplink and downlink antennas may require antenna alignments.

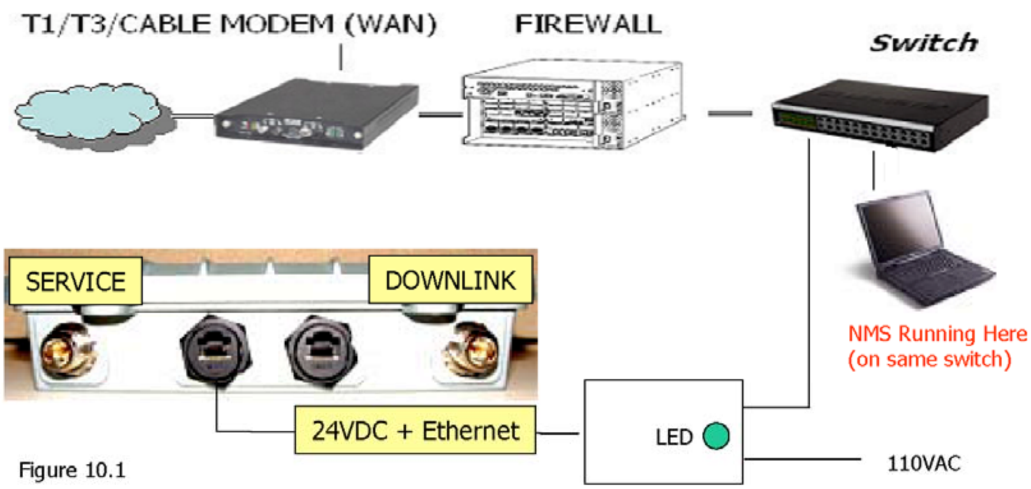



Figure 10.1

1. Mount the Antennas as shown on on the previous page.
2. Connect a cable from the switch to the POE injector (above).
3. Verify internet connectivity on the cable to be plugged into the unit.
4. Power up the POE Injector. The LED on the POE will light up.
5. **Now** connect the Ethernet cable (with power) to the Module.
6. The internal fan should start and is audible, if you put your ear to the box.


7. Insert the 11a/b/g radio card and bring up the Wireless Card utility.
8. Firewalls should be disabled if you wish see the Heartbeats on the NMS.

9. The wireless card utility will show two APs named MESH_INIT and the last numbers of the MAC ID of the radio, for identification purposes. These are the downlink radio and service radio AP of the root node.

Note: On power up the node first senses if there is an Ethernet link on the first Ethernet port. If it senses one, it configures itself as a root node. If no Ethernet link is sensed, the node assumes it is a relay. It's uplink radio then searches for other mesh node downlinks to connect to. It first searches for a root node, failing which it searches for a relay node that has established a chained link back to a root node. If there are multiple relay node candidates, it will connect to the relay that provides the best service, based on test packet transmissions.

10. If the Ethernet cables are "good" then the Ethernet will be sensed and the MESH_INIT_XX will change to StructuredMesh (below). If it does not, check the Ethernet cables and connectivity back to the switch.

Fig. 10.2

| Network | SSID | Type | WEP | Signal | Channel | BSSID |
|---|---|---|---|---|---|---|
| | StructuredMesh | | | 78% | 165 | 00:12:CE |
| | StructuredMesh | | | 63% | 1 | 00:12:CE |

In the image above, one "AP" is on the 5.8GHZ backhaul frequency band (802.11a). This is the root downlink radio. The other radio is the 2.4GHZ AP client service on 802.11b/g. Connect the 11a/b/g radio card to both radios to verify wireless connectivity on both 802.11a and 802.11b/g

1. Mount the Antennas as shown on Figure 10.1. Power up the POE Injector. The LED will light up. Power up the Module. The fan should start and be audible. 4. Bring up the 11a/b/g Wireless Card utility on the laptop.

2. The wireless card utility will show two APs named MESH_INIT and the numbers of the MAC ID of the radio. These are the downlink radio and service radio AP. In general, the downlink radios searches for other mesh nodes to connect to. The Service AP also radio scans to select the best non-interfering channels.

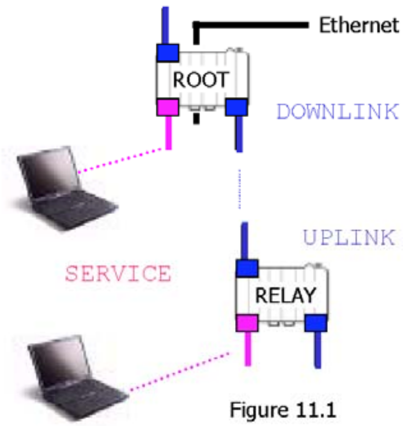
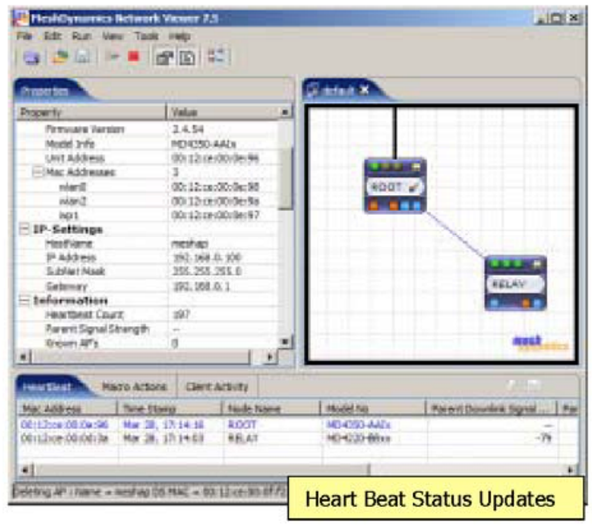



Figure 11.1




3. The relay node "scans" until it finds another node (root or upstream relay) to form a backhaul path. If successful , the MESH_INIT SSID changes to StructuredMesh in 1-2 minutes. If the NMS is running (see NMS User Guide for details), then the ROOT and RELAY nodes should show up based on heart beats sent by nodes.

4. If the radio does not change from MESH_INIT then check to see if the a/b/g wireless radio card can "see" a potential parent downlink to connect to. The radio card utility must show at least one 11a downlink (below)

Figure 11.2


***If the relay uplink antenna cannot "see" a parent downlink, it cannot "connect" to it! Check if:***

- The antenna placement for the uplink and downlink on all nodes are as shown in Fig 9.1
- The node uplink antenna is of the right type for the backhaul frequency band
- The parent downlink antenna is of the right type for the backhaul frequency band
- The antennas connections for uplink, downlink and service are as described earlier
- The relay uplink and parent downlink antennas are approximately at the same height
- The relay uplink and parent downlink antennas are both aligned to the vertical
- There are no obstructions between the two antennas (clear line of sight)
- There are no high voltage or other RF interference sources near the relay
- The antennas are not within 1 meter (3 feet) of any metal structures
- If unit was field upgraded: check if pigtails are firmly connected to the radios.
- If unit was field upgraded: check if pigtails are not damaged, using an ohm meter.

# Trouble Shooting Basics

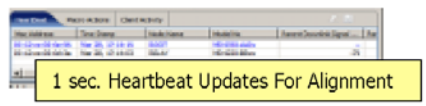
These frequently asked questions were compiled by our Tech Support.
Please contact your applications engineer if you have questions not addressed here.

**Q. Can the NMS be running in the field over a wireless connection?**
A. Yes, connect your radio card to the SSID of either the downlink or service radios to receive node heartbeats

**Q. The Root Node does not show on the NMS.**
A. There could be many reasons for this: First the "Root" did not detect the Ethernet connection from the switch and therefore configured itself as a relay, in search of a root. Replace the Ethernet cables and reboot the node. The second possibility is that the root node is indeed "up" (as seen by a radio card, Fig 11.2) but the heart beats to the NMS are being blocked by a firewall on the computer.

**Q. The Relay Node does not show on the NMS.**
A. The Relay node uplink radio has to "hear" the Root node downlink radio. The beams from the antennas have to intersect each other. The heartbeats show signal strength and transmit rate from parent to child node. Set the heartbeat rate for the relay to 1 sec. Align the relay antenna based on the changes to the signal strength shown by the heartbeats Repeat the steps above with the Root Node – setting its heart beat to 1 second also.

<u>Note</u>: Rotate omni directional antennas during alignment.
Sometimes the "wire" is not well aligned inside the tubing.




**Q. The laptop connects to the node but the signal strength is weak.**
A. Recall that the factory default SSID setting for both 802.11a downlinks and 802.11b service radios is the same: StructuredMesh. Your computer may not be connecting to the nearest radio. Change the SSID on the radios: e.g. Relay80211A, Relay802.11b, connect to the radio of interest and then check signal strength.

**Q. The laptop connects to the node but range is less than expected.**
A. The 2.4Ghz service radio supports 3 modes: 802.11b only, b and g, g only. 802.11g provide more bandwidth, than 802.11b but at the cost of range. Change the settings from the NMS to b only, if more range is needed. Also the radio power settings slider bar should be at 100%.

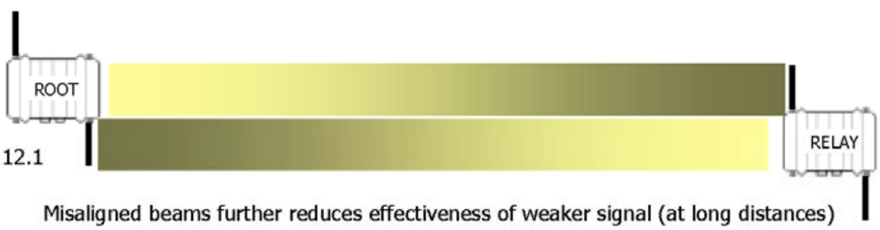



Figure 12.1

Misaligned beams further reduces effectiveness of weaker signal (at long distances)

**Q. The Root and Relay work well at short distances but not as the distance is increased.**
A. The most common cause is poor antenna alignment. The signal is weaker at longer distances and the effect of misalignment more pronounced (above). Check cables, radio pigtails also, in case of field upgrades.

**Q. The overall throughput is poor, despite a good signal strength between backhaul radios.**
A. Bandwidth reduces with retries. Retries occur when packets are not correctly received. This could be due to external RF interferences. Move the antennas to another location or change the channels manually to see if that helps. For long range (beyond IEEE 802.11 default settings) change ACK timing for both downlink and uplink.

***If your question is not addressed above please do email us at techsupport@meshdynamics.com***

Under normal circumstances, there should be no reason to open the module. This page addresses cases where lower power radios are being replaced with higher power units or a 4rth radio is added (see C,D below).

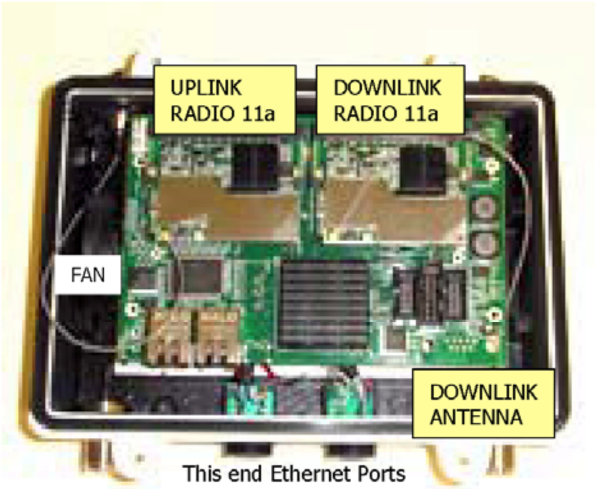



Figure 13.1

Radios are replaced when radio output power has to be increased (for more range) or when a 4th radio is added for mesh node mobility- the scanning radio.

**A. Replacing Uplink and Downlink Radios**

1. Remove all power and wait for 10 seconds.
2. Release any static before opening the box
3. Remove the upper lid from the box
4. Disconnect the pigtails by applying low pressure
5. Replace radios. Locations shown on left.
6. Snap in pigtail connections
7. Attempt to pull off the pigtail, it should be secure.
8. Re-fasten the upper lid.

**B. Replacing the Service Radio**

1. Remove all power and wait for 10 seconds.
2. Release any static before opening the box
3. Remove the upper lid from the box
4. Remove pigtails for the uplink and downlinks
5. Remove the 4 screws holding down the board
6. Turn the board over, (as shown left)

*Verify that Ethernet ports are on the Bottom Right.*

7. Disconnect the pigtails by applying low pressure
8. Replace radios. Locations shown on left
9. Snap in pigtail connections
10. Attempt to pull off the pigtail, it should be secure.
11. Screw the board back..
12. Snap back the pigtails for the backhaul radios.
13. Re-fasten the upper lid

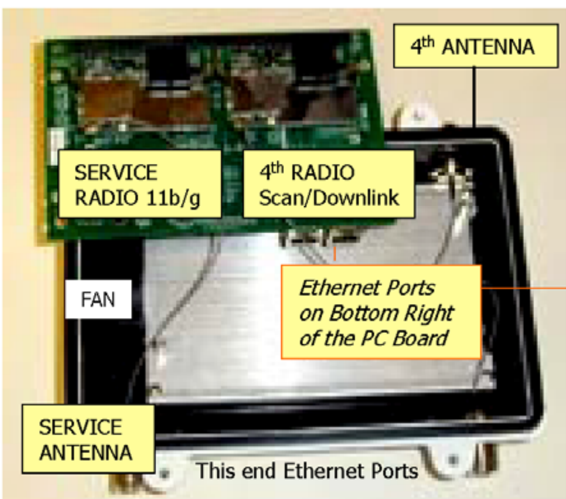



Figure 13.2

**C. Adding a 4rth Radio for Mesh Mobility**
Refer to Section B above and Figure on left.

**D. Adding a 4rth Radio for 2 Downlinks**
Refer to Section B above and Figure on left.
Assumes sectored Antennas being used.

In situations where the uplink-downlink wireless connectivity is weak, adding a diversity antenna may help.

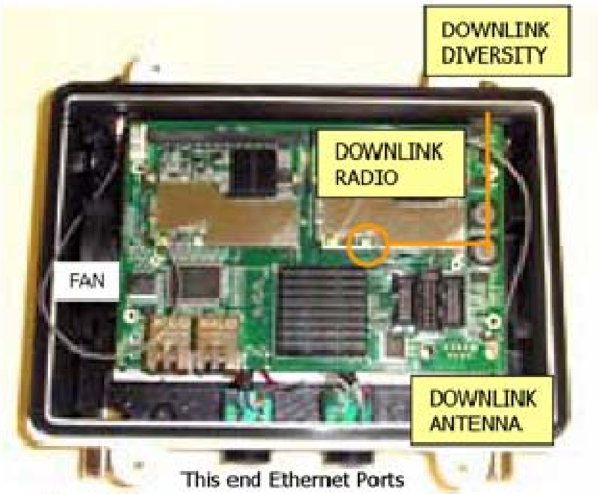



Figure 14.1

**Adding Diversity Downlink for Root Nodes**

For **root** nodes, adding a diversity downlink antennas improves the backhaul link to relay nodes. The 4rth N-Female connecter, if unused, may be used to this purpose (left).

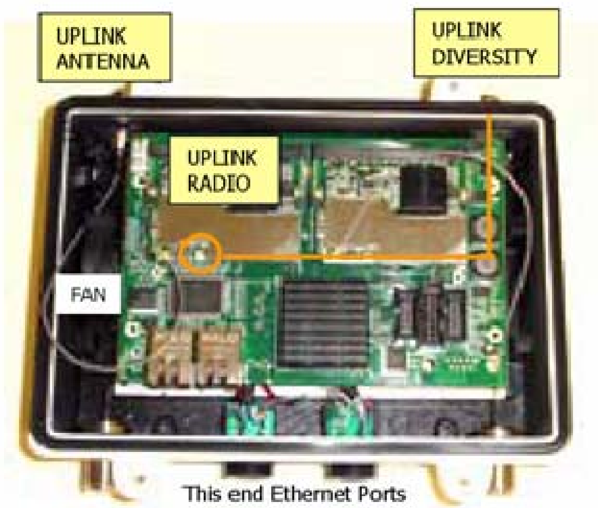



Figure 14.2

**Adding a Diversity Uplink for Relay Nodes**

For **relay** nodes, adding a diversity uplink antenna improves backhaul link to upstream nodes. The 4rth N-Female connecter, if unused, may be used to this purpose (left).

# APPENDIX C. METHODOLOGY_TESTING_WLAN_CHARIOT

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# Methodology for Testing Wireless LAN Performance with Chariot

# Introduction

Whether you want to evaluate the performance of wireless LANs (WLANs) in an informal way or through precise benchmarking procedures, the first step is to understand the factors involved. The ease of setting up and using WLANs makes it easy to overlook many crucial factors and their resulting performance variations. These performance variations can be extreme, however, and they make all the difference in the cost, security and viability of a wireless network.

This white paper describes the factors that affect a WLAN's throughput and coverage, then provides a detailed methodology using NetIQ's Chariot test tool for those who want to benchmark throughput and coverage in a disciplined way.

## An Overview of Throughput and Coverage Factors

A WLAN generally consists of an access point (AP) that connects to a wired network and remote devices (client) that connect to the access point through wireless (radio) links. Throughput is defined as the speed with which a user can send and receive data between a remote device and the access point. Throughput varies across the WLAN's coverage area. This section profiles the main factors that determine WLAN throughput and coverage.

**1. 802.11 Protocol**—The IEEE 802.11 standard defines various physical-layer rates for different types of WLANs, such as 1, 2, 5.5 and 11 Mbps for 802.11b and 802.11g. Rates for 802.11a and 802.11g include 6, 9, 12, 18, 24, 36, 48 and 54 Mbps. The user throughput is less than these link rates for several reasons:

- Each packet includes additional data, such as preambles, headers (MAC, IP, TCP, etc.) and checksums.
- When every directed (unicast) packet is received, the receiver transmits a short acknowledge packet back to the sender.
- Transmitters wait for short random times between packets to allow other users to contend for and share the channel.

Given these reasons, the theoretical maximum user-level performance for the various 802.11 systems is:

| | Number of Channels | Modulation | Maximum Link Rate | Maximum TCP Rate | Maximum UDP Rate |
|---|---|---|---|---|---|
| 802.11b | 3 | CCK | 11 Mbps | 5.9 Mbps | 7.1 Mbps |
| 802.11g (with 11b) | 3 | OFDM/CCK | 54 Mbps | 14.4 Mbps | 19.5 Mbps |
| 802.11g (11g-only mode) | 3 | OFDM/CCK | 54 Mbps | 24.4 Mbps | 30.5 Mbps |
| 802.11a | 19 | OFDM | 54 Mbps | 24.4 Mbps | 30.5 Mbps |
| 802.11a TURBO | 6 | OFDM | 108 Mbps | 42.9 Mbps | 54.8 Mbps |

Table 1-1 assumes 1500-byte packets, encryption enabled, default 802.11 MAC configurations, zero packet errors, and maximum available channel bandwidth (that is, operating at close range). Note that some 802.11 implementations use tricks such as reducing backoff times between packets to improve throughput performance. Such tricks can result in interoperability problems with other vendors' systems.

Table 1-1 also shows two rates for 802.11g to account for the lower rates in 802.11b compatibility mode. The throughput of an 802.11g WLAN decreases significantly in 802.11b compatibility mode because every 802.11g (OFDM) packet needs to be preceded by a CTS packet exchange recognizable by legacy 802.11b devices. With no 802.11b devices connected, an 802.11g network can operate in 11g-only mode and should achieve the standard throughput of 802.11a. The current 802.11g draft standard also provides for a slower RTS/CTS header (instead of CTS-only) when in 802.11b compatibility mode, which will further reduce the 14.4 Mbps TCP/IP rate to 11.8 Mbps.

You therefore have two choices with 802.11g networks: You can achieve high rates comparable with those of 802.11a networks. Or you can get 802.11b compatibility. You cannot have both at the same time.

**Since the key feature of 802.11g is backward compatibility with 802.11b, throughput tests should be done with an 802.11b client device connected to the access point but otherwise idle**. This setup ensures that the 802.11g network is operating in an 802.11b compatible mode.

**2. The radio environment**—Several issues affect the way the radio signal travels from one device to another:

- Radio energy attenuates when it propagates. As radio waves propagate outwards spherically, the energy spreads over an ever-increasing area. In free space, doubling the distance decreases the received power by a factor of 4—the so-called 1/r2 behavior. Radio signals also attenuate when they pass near or through objects such as floors, walls, furniture and people. The attenuation increases with the object's conductivity (due to metal or water content, for example). The combination of these two attenuation effects reduces radio signal strength by 1/r3 to 1/r4, or even 1/r5. In other words, each time you double the distance, the received power might decrease by 8 to 16 times.

- Antenna designs affect how much radio-frequency (RF) energy is transmitted or received and where it is directed.

- Scattering and multi-path cause fading effects. Signal strength can change rapidly as a function of location because the received signal is the sum of potentially numerous signals scattered from nearby objects. As the transmitter or other objects in the environment move, the scattered signals sometimes add together and sometimes cancel each other. Fading can change significantly over distances of a wavelength or so (12.5cm at 2.4 GHz and 6 cm at 5 GHz). Fading also occurs over time as well as location. Even small changes in the environment (for example, people or other objects moving) can affect the fading pattern. This means that the received signal strength can also change quite quickly over time, even when the receiver and transmitter are fixed.

- Scattering and multi-path results in delay spread. The received signal might contain several slightly delayed copies of the transmitted signal, as the scattered signals travel via different physical paths of different lengths.

- Other devices occupying the same or nearby channels cause interference. For example, the 2.4 GHz spectrum might be occupied by Bluetooth devices, microwave ovens, and cordless telephones.

**3. Frequency**—A common misconception is that free-space propagation depends upon frequency, so higher frequencies are assumed to propagate less well than lower frequencies. As a good counter example to this misconception, consider visible light, which is simply an ultra-high frequency electromagnetic wave that propagates perfectly well across large distances.

On the other hand, effects such as antenna efficiency, RF component performance, and absorption through and scattering around objects do depend upon frequency. Here are some of the frequency-dependent effects:

- Generally, antennae of the same physical size tend to become more directional (have higher gain in some directions and less in others) as the frequency increases. Advantage: 5 GHz.

- Absorption due to propagation through objects tends to increase with frequency. Advantage: 2.4 GHz.

- Scattering around objects might have a positive or negative effect on signal strength as a function of frequency, depending upon the relative sizes and locations of the objects. Advantage: Neutral.

- Noise and spurs generated by nearby electronics (for example, inside the AP or PC laptop) in addition to co-channel interference, such as Bluetooth devices, cordless phones and microwave ovens, will degrade 2.4 GHz sensitivity more than 5 GHz. Advantage: 5 GHz.

- Cable loss increases with frequency, so antenna cables (if present) in the AP or laptop will have more loss at high frequency, unless more expensive cables are used. Advantage: 2.4 GHz.

In more open environments, there will be little difference between 2.4 GHz and 5 GHz propagation. For example, measurements of 2.4 GHz and 5 GHz propagation done by WJ Communications in two indoor environments show little difference between 2.4 GHz and 5 GHz propagation. See the full paper at
http://www.watkins-johnson.com/pdf/techpubs/Indoor_prop_and_80211.pdf

Typically, the OFDM modes of 2.4 GHz 802.11g networks will have slightly less coverage than 2.4 GHz 802.11b networks. Depending upon the propagation environment, the coverage of 5 GHz 802.11a networks might be similar to, or in some cases less than, that of 802.11g networks. The differences between 2.4 and 5 GHz propagation are generally insignificant compared to the differences between one vendor's equipment and another's, however. An 802.11a product from one vendor might have better coverage than an 802.11g product from another vendor.

**4. The vendor equipment design**—Equipment from different vendors exhibit significantly different performance due to architecture, design, manufacturing and software variations, as well as proprietary features and enhancements.

**5. Vendor interoperability**—Products that undergo Wi-Fi certification are certified to interoperate with a wide variety of vendors' products. However, these tests mainly verify basic connectivity and do not enforce stringent throughput requirements. You might be able to connect a client device to a different vendor's access point, but you might not be getting very high throughput. Products that provide good performance (throughput, coverage, etc.) when connected to a variety of different vendor's devices are clearly more desirable.

**6. Security**—Security includes encryption and authentication. Encryption protects WLAN traffic from eavesdropping and other attacks such as replay or man-in-the-middle attacks. Authentication validates the users' credentials (ensuring that the user is who they say they are) and also possibly validates the network's credentials (ensuring that the network is what it says it is, and not someone masquerading as the network).

WLAN security standards have progressed from WEP to TKIP and WPA and now to AES (the Advanced Encryption Standard), with significant security enhancements at each stage. No matter what security standard is involved, the way the standard is implemented can affect the WLAN's performance. Specifically, some vendors implement encryption in software, which can dramatically reduce throughput compared to advertised rates. When evaluating performance, it is vital to measure throughput with encryption enabled. For more details, see http://www.atheros.com/pt/atheros_wlansecurity.pdf.

## Measuring Throughput and Coverage

The throughput of WLANs depends heavily on the environment, including the distance between the client and the access point. The throughput generally falls off as distance increases, but factors such as obstructions (like furniture, people, or walls of different construction) also have a significant effect. Throughput does not depend upon distance alone. It is possible to have distant test locations that produce higher data rates than closer locations. Moreover, the peak data rate measured at short distances is not the most important factor in the user's experience. Rather, the rate the user experiences at a variety of distances and locations is a very important factor. Therefore, it is critical to measure WLAN throughput at a variety of locations, including some far from the access point.

WLAN environments generally fall into three categories:

- Outdoor: typically a direct line of sight between the access point and client. Examples include outdoor campus coverage, public areas, or even inside large, open buildings such as airport concourses or convention halls.
- Open office: no longer a direct line of sight between the access point and client, but typically at most two-to-three obstructions such as walls. Examples are warehouses or offices containing cubicles, lobbies and meeting areas.
- Closed office: no direct line of sight, with many obstructions between the access point and the client. Examples are buildings with regular offices and many walls.

WLAN coverage differs significantly in these different environments. Outdoor WLANs provide the longest ranges and closed-office WLANs the shortest. Different construction techniques also have a significant impact on coverage and throughput. For instance, concrete walls attenuate signals more than stud walls with sheet rock. In general, the relative performance and throughput for different products under test should be similar across the different environments. So if Vendor #1's product is significantly better than Vendor #2's in an open-office environment, it is highly likely (although not guaranteed) that it will be significantly better in other environments. It is possible (although more time consuming) to test products across several different environments to accurately determine the relative performance.

Chariot from NetIQ can be used to measure the throughput the user will experience. Typically Chariot is used to measure TCP throughput in megabits per second (Mbps) in either the uplink direction (for example, upload from the client to the AP) or downlink direction (for example, download from the AP to the client). Downlink TCP performance is the most relevant metric, since it reflects the most common usage such as browsing the web or downloading email.

Some applications like video streaming use a simpler protocol called UDP or RTP. Generally, UDP performance numbers will be 15-20 percent higher than TCP performance numbers because there is less protocol overhead associated with UDP.

Refer to Appendix A for details on test setup.

## Test Setup

The first step is to decide which products will be tested and which access points will be tested with which client cards. The natural test configuration is to pair the access point and client from the same vendor. However, it is also important to assess how well a client card performs with other vendor's access points, since many users will use their client devices in many different networks.

An example of test configurations with natural pairing:

- Test 1: Vendor 1 access point with Vendor 1 client.
- Test 2: Vendor 2 access point with Vendor 2 client.
- Test 3: Vendor 3 access point with Vendor 3 client.

An example of test configurations where just client devices are being tested against a 3rdparty access point:

- Test 1: Vendor 4 access point with Vendor 1 client.
- Test 2: Vendor 4 access point with Vendor 2 client.
- Test 3: Vendor 4 access point with Vendor 3 client.

An example of test configurations where interoperability is being tested:

- Test 1: Vendor 1 access point with Vendor 1 client.
- Test 2: Vendor 1 access point with Vendor 2 client.
- Test 3: Vendor 2 access point with Vendor 1 client.
- Test 4: Vendor 2 access point with Vendor 2 client.

The second step in designing the test procedure is to choose a set of test locations:
Select a test location for the access point. Ideally the access point should be located high above the floor and away from immediate obstructions. Most importantly, use exactly the same access point location for each product tested.

- Select a channel for testing, and verify that the RF environment on the selected channel is clear. Use a sniffer or client device to check that there are no access points or ad-hoc networks located on the same channel throughout the test area. For 11b and 11g, this means no overlapping channel; channels with number spacing of 4 or less overlap and cause significant in-band interference. For example, 2.4 GHz channel 1 overlaps with channels 2, 3, 4, 5, and channel 6 overlaps with channels 2, 3, 4, 5, 7, 8, 9 and 10. For 11a the standard 54 Mbps channels do not overlap.

- Select at least eight test locations at a variety of locations and distances from the access point (see Figure 1-1). At least one test location should be at the limit of coverage. (If you later discover that one product under test has much better coverage than initially expected, then additional, more remote, test locations need to be added and the earlier tests with the other equipment to be repeated at these new locations.)

- All wireless LANs have a limit on signals that are too strong. Some WLAN products may actually produce low data rates at very close ranges (for example, less than 3 feet). Therefore, the closest test points should be no less than 5 feet apart.

The key criterion is repeatability. For each product under test, the access point locations, software setup, channel used, overall environment, test procedure and test locations should be the same. Environmental repeatability is generally improved if the tests are done backto- back, for example, over as short an elapsed time as possible.

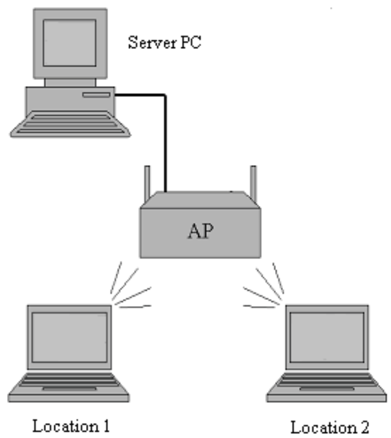


**Figure 1-1. Typical Range and Throughput Setup**

At each location, make a minimum of three measurements so you can average-out some of the local radio fading effects by repeating a measurement with a small shift in the test laptop's location. This strategy improves the test's repeatability and makes the results less prone to "lucky" or "unlucky" measurements each time the test is repeated.

Thus, at each test location, repeat at least three times:

- Measure the downlink and uplink TCP (and optionally UDP) throughput.
- Displace the test laptop by about one wavelength (that is, between 12.5 cm at 2.4 GHz and 6 cm at 5 GHz) and repeat. Alternatively (or additionally), rotate the laptop by 45 degrees or more.

As different products are tested, use the identical procedure (test setup, software, locations and displacements or rotations).

## Test Procedure

Putting all the previous steps together, the overall test procedure is:|

1. Setup test #1: Install the access point from Vendor #1, and client card #1.

2. Go to the first test location and make at least three measurements, moving the location and/or orientation of the laptop slightly between measurements.

3. For each location, record the throughput (TCP downlink, TCP uplink, and optionally UDP downlink and uplink) for each run. Record the test locations on a floorplan.

4. Repeat steps 2-3 for each test location.

5. Repeat steps 1-4 for each different equipment configuration.

## Performance Metric

A combined metric, or score, of throughput and coverage can be computed from the measurements. Both high throughputs and large coverage areas are desirable.

The metric should be proportional to the measured throughput. For example, if one product produced exactly twice the throughput at each location compared to a second product, its metric is twice as large.

The metric should also be proportional to the coverage area. For example, if one product provides, say, 10 Mbps over a certain area (and no connection outside this area), while a second product provides 10 Mbps over twice the area (and no connection outside), then the score of the second product is twice the first.

To compute this metric, compute the average throughput of the three (or more) measurements at each test location. Also, compute or measure the straight-line distance in meters from each test location to the access point.

The performance metric is the sum over locations of the throughput Mbps(i) multiplied by the ring area over which that throughput is achieved:

$$Performance\ Metric = 10^{-3} \times \sum_{i=1}^{n} Mbps(i) \left[ r^2(i) - r^2(i-1) \right]$$

n is the number of locations at which measurements were made. The range r(i) is squared because area is proportional to the square of the distance. The normalization factor 0.001 is included to make the end figures more tractable. The area of the previous range r(i-1) is subtracted from the current range to obtain the ring area. As a rule, r(0) is the origin and has zero value.

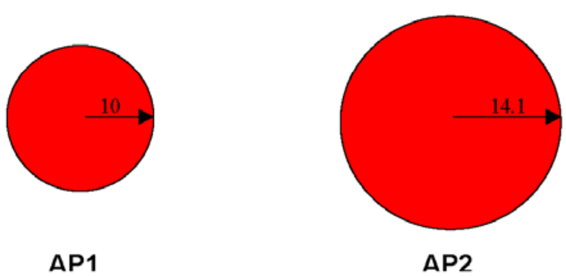


**Figure 1-2. Same Throughput Over Different Coverage Radii.**

As a first example, consider two access points, AP1 and AP2 (see Figure 1-2). Both provide 20 Mbps coverage up to a certain point and drop off immediately after that point. In this case, there is only one measurement location, so $n = 1$. Assume that the range of coverage for AP1 is 10 meters, while that for AP2 is 14.1 meters. The performance metric for AP1 is 2.0, while that for AP2 is 4.0. This metric is consistent with the fact that AP2 provides twice the coverage area as does the AP1.

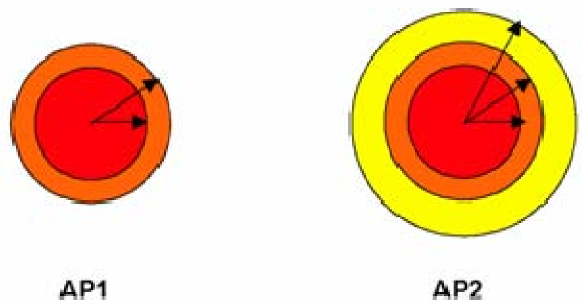


**Figure 1-3. Different Throughput Over Different Coverage Radii.**

Consider a second example in which AP1 provides higher average throughput at close range but smaller overall coverage area than AP2 does (see Figure 1-3). Specifically, the average throughput at the various ranges are as follows:

| Measurement Location (m) | AP1 Throughput (Mbps) | AP2 Throughput (Mbps) |
|---|---|---|
| r(1) = 30 | 20 | 18 |
| r(2) = 70 | 15 | 13 |
| r(3) = 100 | 0 | 10 |

The performance metric for AP1 is $0.001\ ([20(30^2 - 0) + 15(70^2 - 30^2) + 0(100^2 - 70^2)] = 78$. The performance metric for AP2 is $0.001\ ([18(30^2 - 0) + 13(70^2 - 30^2) + 10(100^2 - 70^2)] = 119.2$.

Thus, the performance metric is truly a function of both average throughput and range. At the far edges of coverage, extra range contributes greatly to the performance metric, due to the squared dependency. What the performance metric is truly quantifying is system capacity, that is, a system's ability to deliver high data rates across as wide an area as possible. In the above example, AP2 delivers far greater system capacity because of its extended range of coverage, even though its average data rates are lower than those of AP1.

# Appendix A: Chariot Test Setup

A common step that should precede any of the steps outlined below is a wired throughput check. A crossover Ethernet cable should be used to connect the server PC and the laptop being used for range testing. In this way, the performance of the peripheral busses on the PCs, as well as the functionality of the test programs, can be verified. A 100-Mbps Ethernet connection should register TCP throughput of 85-90 Mbps in this configuration. Verification of this increases the confidence that the performance of the wireless link is not affected by host hardware issues.

Furthermore, the server PC should reside on an independent subnet or network from the corporate network. This ensures that the server PC-to-AP connection is not affected by traffic outside of the test setup.

Chariot can then be used to measure the throughput that can be expected by the user of the wireless network. Through the use of application scripts, Chariot generates network traffic and measures performance metrics such as throughput and response time across a range of protocols, including TCP, UDP, RTP, and IPX.

Chariot generates traffic using skinny software agents called Performance Endpoints. Therefore, setup of the Chariot test environment requires the installation of an Endpoint at the server and the client. The Chariot console should also be installed on the client to control the test and to collect and display the results. NetIQ's Performance Endpoints can be downloaded from http://www.netiq.com/support/pe/pe.asp. Once the Endpoints have been installed, only the IP addresses of the Endpoints need to be entered into the Chariot environment for test runs to begin.

Chariot ships with default test scripts denoted by the .scr suffix. They serve as the starting blocks with which to build customized test scripts. In particular, the scripts Filercvl.scr and Filesndl.scr are useful for testing sustained throughput performance with large amounts of data transfer.

One of the key features of Chariot is the ability to view the time series of the measurement parameter under consideration. An example screen shot capturing throughput performance is shown in Figure 1-4.

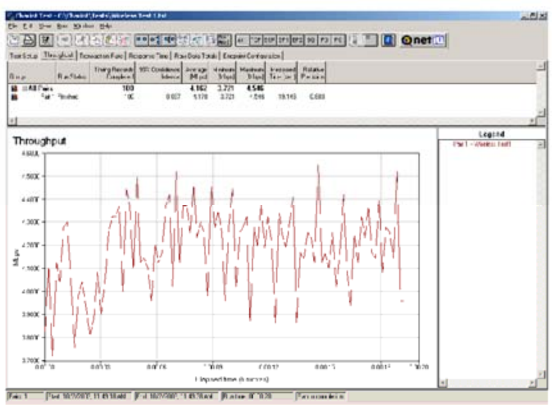


**Figure 1-4. NetIQ Chariot Throughput Test**

In your testing, you will likely want to compare different wireless technologies or the throughput achieved between different combinations of clients and access devices. The Compare Test feature in Chariot (see Figure 1-5) makes comparisons simple and straightforward.

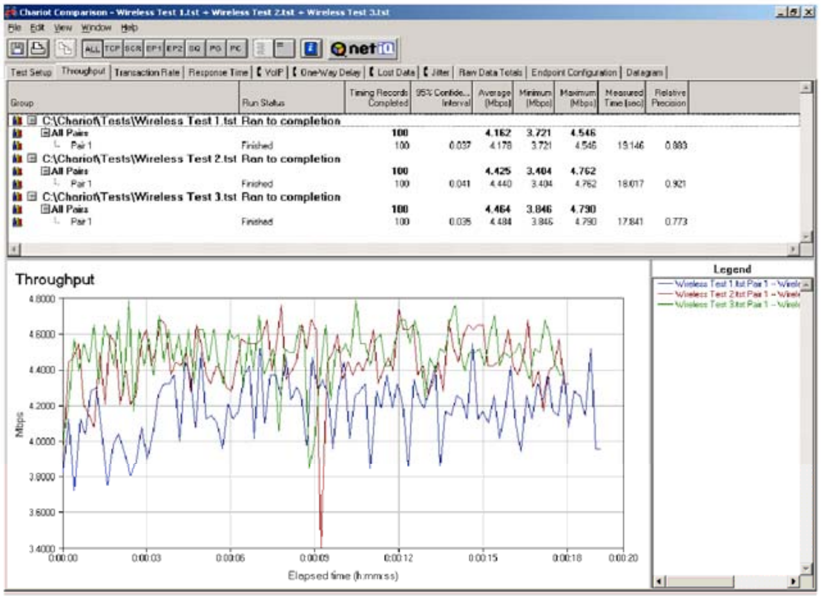

**Figure 1-5. Comparison of multiple Chariot test results**

For more information about Chariot, or to request an evaluation, go to http://www.netiq.com/products/chr/ or contact your local NetIQ reseller.

**NOTE:** This document may be updated periodically. Please check the Atheros or NetIQ web sites for the latest version.

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# APPENDIX D. KESTREL_SPECS.PDF

**Kestrel® Pocket Weather Meters Specifications**

| Measurement *Response Time* | Model | Units | Operational Range | Resolution | Accuracy (+/-) | Specification Range |
|---|---|---|---|---|---|---|
| Wind Speed (Air Velocity) *1 second* | All Models | m/s | 0.4 to 60.0 m/s | 0.1 | Larger of 3% of reading or least significant digit | 0.4 to 40.0 m/s |
| | | ft/min | 59 to 11,948 ft/min | 1 | | 59 to 7877 ft/min |
| | | km/h | 1.0 to 218.0 km/h | 0.1 | | 1.0 to 144.0 km/h |
| | | mph | 0.8 to 135.0 mph | 1 | | 0.8 to 89.0 mph |
| | | knots | 0.6 to 118.3 kt | 0.1 | | 0.6 to 78.0 kt |
| | | Beaufort | 0 to 12 B | 0.1 | | 0 to 12 B |
| 1 inch diameter impeller with precision axle and sapphire bearings. Off-axis accuracy -1% @ 5º off-axis; -2% @ 10º; -3% @ 15º. Calibration drift < 1% after 100 hours use at 16 MPH / 7 m/s. Sustained operation above 60 MPH / 27 m/s will wear impeller rapidly and may cause destruction of impeller. Replacement impeller (NK PN-0801) may be field-installed without tools (US Patent 5,783,753). | | | | | | |
| Air Flow *1 second* | 4100 | cfm | 0 to 99,999 cfm | 1 | 3% of reading | 0 to 99,999 cfm |
| | | $m^3/h$ | 0 to 99,999 $m^3/h$ | 1 | | 0 to 99,999 $m^3/h$ |
| | | $m^3/m$ | 0 to 99,999 $m^3/m$ | 1 | | 0 to 99,999 $m^3/m$ |
| | | $m^3/s$ | 0.0 to 9,999.9 $m^3/s$ | 0.1 | | 0.0 to 9,999.9 $m^3/s$ |
| | | L/s | 0 to 99,999 L/s | 1 | | 0 to 99,999 L/s |
| Automatically calculated from Air Velocity measurement and user-specified duct shape (circle or rectangle) and dimensions (units: in, ft, cm or m). Maximum duct dimension input: 258.0 in / 21.5 ft / 655.3 cm / 6.55 m. | | | | | | |
| Temperature *1 second* | 2000 2500 3000 3500 4000 4100 | °F | -49.0 to 257.0 °F | 0.1 | 1.8 °F | -20.0 to 158.0 °F |
| | | °C | -45.0 to 125.0 °C | 0.1 | 1.0 °C | -29.0 to 70.0 °C |
| Measures air, water and snow temperature. Thermally isolated, hermetically sealed, precision thermistor mounted externally (US Patent 5,939,645). Calibration drift negligible. | | | | | | |
| Relative Humidity *1 minute* | 3000 3500 4000 4100 | % RH | 0.0 to 100.0 % | 0.1 | 3.0 %RH | 5.0 to 95.0 % non-condensing |
| Polymer capacitive humidity sensor mounted in thin-walled chamber external to case for rapid, accurate response (US Patent 6,257,074). (To achieve stated relative humidity accuracy, unit must be permitted to equilibrate to external temperature when exposed to large, rapid temperature changes and must be kept out of direct sunlight.) Calibration drift +/- 2% over 24 months. Relative humidity may be recalibrated at factory or in field using Kestrel Humidity Calibration Kit (NK PN-0824). | | | | | | |
| Pressure *1 second* (*mb & PSI 4000 model only*) | 2500 3500 4000 | inHg | 8.86 to 32.48 inHg | 0.01 | 0.05 inHg | At 77.0 °F, <19,700 ft |
| | | hPa / mb | 300.0 to 1100.0 hPa / mb | 0.1 | 1.5 hPa / mb | At 25.0 °C, <6,000 m |
| | | PSI | PSI | 0.1 | PSI | At 77.0 °F, <19,700 ft |
| Monolithic silicon piezoresistive pressure sensor with second-order temperature correction. Maximum error beyond specified temperature, +/- 0.09 inHg / 3.0 hPa. Calibration drift typically -0.03 inHg / -1.0 hPa per year. Pressure sensor may be recalibrated at factory or in field. | | | | | | |
| Altitude *1 second* | 2500 3500 4000 | ft | -6000 to 30000 ft | 1 | 50 ft | At 77.0 °F, <19,700 ft. Max error +/- 98 ft |
| | | m | -2000 to 9000 m | 1 | 15 m | At 25.0 °C, <6,000 m. Max error +/- 30 m |
| Temperature compensated pressure (barometric) altimeter. | | | | | | |
| Wind Chill *1 second* | 2000 2500 3000 3500 4000 4100 | °F | 0.7 to 135.0 MPH, -49.0 to 257.0 °F | 0.1 | 1.8 °F | 1.8 to 89.0 mph, -50.0 to 50.0 °F |
| | | °C | 0.4 to 60.0 m/s, -45.0 to 125.0 °C | 0.1 | 1.0 °C | 0.4 to 40 m/s, -45.6 to 10.0 °C |
| Calculated from the primary measurements of wind speed and temperature. Utilizes the NWS Wind Chill Temperature (WCT) Index, revised 2001, with wind speed adjusted by a factor of 1.5 to yield equivalent results to wind speed measured at 10 m above ground. (Specification temperature limits established by WCT Tables.) | | | | | | |
| Heat Index *1 minute* | 3000 3500 4000 4100 | °F | 0.0 to 100.0 %RH, -49.0 to 257.0 °F | 0.1 | 3.6 °F | 70.0 to 130.0 °F, 0 to 100% RH |
| | | °C | 0.0 to 100.0 %RH, -45.0 to 125.0 °C | 0.1 | 2.0 °C | 21.1 to 54.4 °C, 0 to 100 %RH |
| Calculated from the primary measurements of temperature and relative humidity. Utilizes the NWS Heat Index (HI) tables. (Specification temperature limits established by HI tables.) | | | | | | |
| Dewpoint *1 minute* | 3000 3500 4000 4100 | °F | 0.0 to 100.0 %RH, -49.0 to 257.0 °F | 0.1 | 3.6 °F | -20.0 to 158.0 °F, 20.0 to 95.0% RH |
| | | °C | 0.0 to 100.0 %RH, -45.0 to 125.0 °C | 0.1 | 2.0 °C | -29.0 to 70.0 °C, 20.0 to 95.0 %RH |
| Calculated from the primary measurements of temperature and relative humidity. Temperature to which the air would need to be cooled at a constant pressure to become saturated. | | | | | | |
| Wet Bulb Temperature *1 minute* | 3000 3500 4000 | °F | -49.0 to 257.0 °F, 0.0 to 100.0 %RH, 8.86 to 32.48 inHg | 0.1 | 3.6 °F | 32.0 to 100.0 °F, 5.0 to 95.0% RH, 8.86 to 32.48 inHg, <19700 ft |
| | | °C | -45.0 to 125.0 °C, 0.0 to 100.0 %RH, 300.0 to 1100.0 hPa | 0.1 | 2.0 °C | 0.0 to 37.8 °C, 5.0 to 95.0 %RH, -2000.0 to 9000.0 hPa, <6000 m |
| Calculated from the primary measurements of temperature, relative humidity and pressure. Temperature indicated by a wet bulb psychrometer. | | | | | | |
| Density Altitude *1 second* | 4000 | ft | -49.0 to 257.0 °F, 0.0 to 100.0 % RH, 8.86 to 32.48 inHg | 1 | 246 | 32.0 to 100.0 °F, 5.0 to 95.0 %RH, 8.86 to 32.48 inHg, <19700 ft |
| | | m | -45.0 to 125.0 °C, 0.0 to 100.0 %RH, 300.0 to 1100.0 hPa | 1 | 75 | 0.0 - 37.8 °C, 5.0 to 95.0 %RH, -2000 to 9000 hPa, <6000 m |
| Calculated from the primary measurements of temperature, relative humidity and pressure. Air density converted to equivalent sea level elevation at the International Standard Atmosphere. | | | | | | |

| | | |
|---|---|---|
| Max / Average Wind Speed (Air Velocity) | All Models | One-button clear and restart of Max Wind Gust and Average Wind measurement. |
| Pressure Trend | 2500 3500 | Continuously updating three-hour barometric pressure trend indicator: rising rapidly, rising, steady, falling, falling rapidly. |
| Data Storage / Display | 4000 4100 | Minimum, maximum, average and logged history stored and displayed for every measured value. 480-point data logger with graphical display. Auto data storage; interval settable from 2 seconds to 12 hours. Manual data capture. |
| Data Upload | 4000 4100 | Requires optional PC interface (NK PN-0830) and provided software. RS-232 connection with USB adapter available. |
| Display | 1000 2000 3000 | Reflective 3 1/2 digit LCD. Digit height 0.36 in / 9 mm. |
| | 2500 3500 | Reflective 4 digit LCD. Digit height 0.36 in / 9 mm. |
| | 4000 4100 | Multifunction, multi-digit programmable dot-matrix display. |
| Display Update | All Models | 1 second. |
| Languages | 4000 4100 | English, French, German, Italian, Spanish. |
| Display Backlight | 2000 2500 3000 3500 | Aviation green electroluminescent backlight. |
| | 4000 4100 | Choice of aviation green or visible red (4000 only) electroluminescent backlight. Automatic or manual activation. |
| Clock / Calendar | 2500 3500 | Real-time hours:minutes clock. |
| | 4000 4100 | Real-time hours:minutes:seconds clock, calendar, automatic leap-year adjustment. |
| Operational Temperature Range (LCD and Batteries) | All Models | The operational temperature range of the liquid crystal display and batteries is 14° F to 131° F / -10 °C to 55 °C. Beyond the limits of the operational temperature range, the unit must be maintained within range and exposed for minimum time necessary to take reading. |
| Storage Temperature | All Models | -22 °F to 140 °F / -30 °C to 60 °C. |
| Auto Shutdown | 2000 2500 3000 3500 | After 45 minutes of no key presses. |
| | 4000 4100 | User-selectable: 15 or 60 minutes with no keypresses or disabled. |
| Languages | 4000 4100 | English, French, German, Italian, Spanish. |
| Certifications | All Models | CE certified. Individually tested to NIST-traceable standards (written certificate of tests available at additional charge). |
| Batteries | 2000 2500 3000 3500 | CR2032, one, included. Average life, 300 hours of use, +/-depending on backlight use. |
| | 4000 4100 | AAA Alkaline, two, included. Average life, 400 hours of use, +/-depending on backlight use. |
| Sealing | All Models | Waterproof (IP67 standard). |
| Dimensions | 2000 2500 3000 3500 | Unit 4.8 x 1.7 x 0.7 in / 122 x 42 x 18 mm. Case 4.8 x 1.9 x 1.1 in / 122 x 48 x 28 mm. |
| | 4000 4100 | Unit 5.0 x 1.8 x 1.1 in / 12.7 x 4.5 x 2.8 cm. |
| Weight | 2000 2500 3000 3500 | Unit 2.3 oz / 65 g. Case 1.3 oz / 37 g. |
| | 4000 4100 | Unit 3.6 oz / 102 g. |

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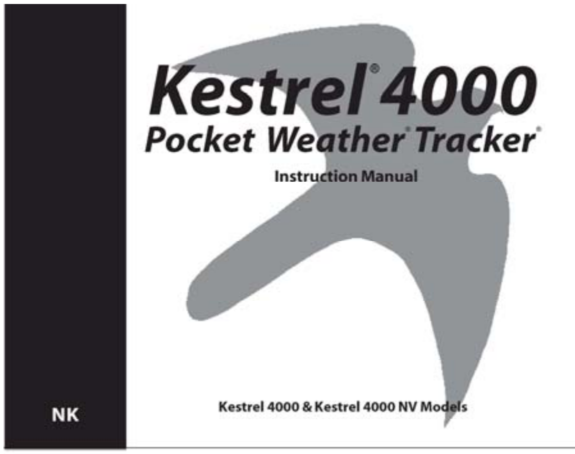
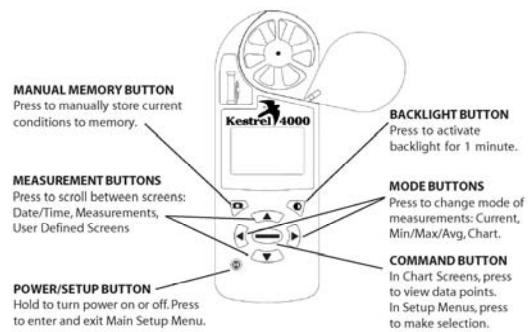
# APPENDIX E.  KESTRAL 4000-V.4.10

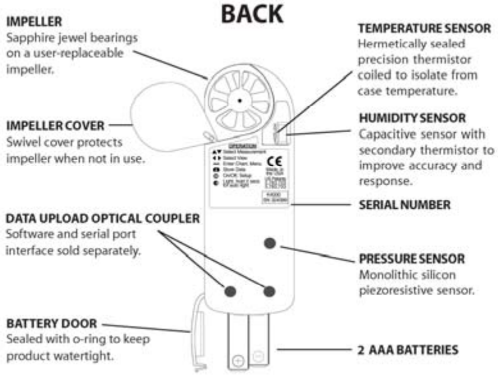



**Kestrel® 4000 Pocket Weather™ Tracker™**
**FRONT**




2

**Kestrel® 4000 Pocket Weather™ Tracker™**
**BACK**




3

Congratulations on the purchase of your Kestrel 4000 Pocket Weather Tracker! The Kestrel 4000 is the next generation of weather monitoring. Now, you can instantly measure EVERY major environmental condition easily, accurately, and right in the palm of your hand.

While the Kestrel 4000 is user-friendly and simple to use (and the Quick Start Card will help get you started), reading the instruction manual is recommended in order to use the Kestrel 4000 to its fullest potential.

NK, manufacturer of Kestrel Pocket Weather Meters, is available to answer questions and provide support. Contact NK by phone: 610.447.1555, fax: 610.447.1577, email: info@nkhome.com, or web: www.nkhome.com.

## Table of Contents



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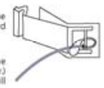
# Getting Started

**Pouch and Lanyards**

Wrist and neck lanyards and a small pouch have been provided. To install the lanyard, feed the thin end of the lanyard around the metal post on the battery door (as shown in diagram). Feed the thick end of the lanyard through the loop on the thin end. Using tweezers can help.



**Battery Installation**

Use only AAA batteries. Install batteries as indicated on the battery door. After installing the batteries, the Kestrel 4000 will automatically start in the Date and Time Setting mode. (See Date and Time Setup below.) Custom settings and chart data will be saved during a battery change; only the date/time and MMA values will be lost.

**Turning the Kestrel 4000 ON and OFF**

**ON:** Press the ⏻ button.

**OFF:** Hold the ⏻ button for two seconds. Or, press the ⏻ button, then press the ▬ button with the word OFF highlighted. (Note: your unit will continue to automatically store data when the power is turned off.)

**Date and Time Setup**

The first time that you turn on your Kestrel 4000, as well as after a battery change, you will need to set the date and time. The Introduction Screen will appear for 3 seconds, followed by the Date/Time Setup Screen. Press the ▲ and ▼ buttons to scroll through the settings. Press the ◀ and ▶ buttons to scroll through the setting options. After entering the date and time, press the ⏻ button to exit the Date/Time Setup. Then press the ⏻ button again to exit the Main Setup Menu.


# Navigation

The Kestrel 4000 is set up to display *10 Measurements* (some are actually calculations) in *3 Modes*. The *Measurements* are listed on the next page with their corresponding screen icon. Use the ▲ and ▲ buttons to scroll through the various Measurements.

The *Modes* are:

**Current** - displays the instantaneous reading
**Min/Max/Avg** - displays the Minimum/Maximum/Average readings from stored data
**Chart** - displays a graphical representation of up to 2000 stored data points for each measurement.

Examples of each of these screens are shown on the next page. Use the ◀ and ▶ buttons to scroll through the various Modes.

In addition to these Measurements and Modes, there are also 3 User Screens, which simultaneously show 3 current measurements (see pages 7 and 11 for more information); and the Date & Time Screen, which gives the current date and time.



**Measurements use ▲▼**

- Wind Speed
- Temperature
- Wind Chill
- Humidity
- Heat Index
- Dew Point
- Wet Bulb
- Barometric Pressure
- Altitude
- Density Altitude

**Measurement Navigation**

Starting on the Date & Time Screen…


…Press the ▼ button to scroll to the Current Wind Speed Screen.


Press the ▼ button again to scroll to the Current Temperature Screen.

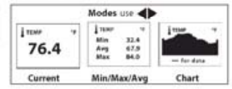

Continue pressing the ▼ button to scroll through the Current Measurement Screens, listed on the previous page, followed by the 3 User Screens. Press the ▲ button to scroll through these screens in reverse order.

**Mode Navigation**

While in a Current Screen, press the ▶ button to view the Min/Max/Avg for a measurement. If there is no stored data, the values will be displayed as "--.-"


Press the ▶ button again to view a chart for the measurement. If there is no stored data, the axis will appear, but the chart will be blank.

Press the ◀ button to return to the Min/Max/Avg and Current Screens. From either Min/Max/Avg or Chart Screen, press the ▼ or ▲ button to scroll through the Min/Max/Avg or Chart Screen for the other measurements.




**Navigation of Charts**

The Kestrel 4000 is capable of storing up to 2000 data points for each measurement. To review the data, press the ▬ button while viewing a chart. A cursor will appear on the most recent data point. Press the ◀ button to scroll through older data points and the ▶ button to scroll through more recent data points. The date and time at which the data was stored will be displayed at the bottom of the screen. The data value will be displayed at the top of the screen. Hold down the ◀ or ▶ button to scroll quickly through the data points.


Press the ▲ or ▼ button to review the data for the other measurements. Please note that the cursor will remain at the same date and time. If new data is stored while viewing chart data, the entire chart will shift left with the new data point charted on the right. The cursor will not shift with the chart.

Press the ▬ button to return to the Chart Mode.



# Special Functions

**User Screens**

The Kestrel 4000 has three User Screens which can be customized to display three current measurements simultaneously. (See page 11 for setup instructions.)


**Min/Max/Avg for Wind Speed and Wind Chill**

The Min/Max/Avg values for Wind Speed and Wind Chill are measured independently from the stored and charted data. While viewing the Min/Max/Avg screen for either Wind Speed or Wind Chill, press the ▬ button when the screen displays "--average" to begin collecting data for both measurements. Press the ▬ button when the screen displays "--stop" to stop collecting data and hold the values on the display. Press the ▬ button when the screen displays "--clear" to clear the data. This routine will work simultaneously for both measurements, regardless of which one is displayed while the routine is run. The Min/Max/Avg for Wind Speed and Wind Chill will not affect any other Min/Max/Avg or stored data.

**Relative Humidity**

The Kestrel 4000 is capable of measuring RH to a high accuracy: +/- 3% RH. To ensure the Kestrel 4000's ability to operate within these specifications, follow these recommendations:

- Avoid taking measurements in direct sunlight, which will heat the air inside the humidity sensor enclosure and cause inaccurate readings.
- If your circumstances force you to expose the Kestrel to a large temperature swing prior to taking a relative humidity reading (such as when taking a Kestrel stored inside at 70° F outside to a temperature of 40° F), you will need to take additional steps to ensure that the Kestrel's external temperature sensor is in thermal equilibrium
  - Ideally, provide an airflow of at least 1 M/S (2.2 MPH, over the temperature sensor, moving from the back of the unit towards the front. (In other words, point the Kestrel into the airflow.) With airflow over the temperature sensors and humidity chambers, readings within specifications will be provided within two to three minutes, even after a large temperature shift.
  - If no airflow can be provided, you must allow sufficient time for the RH value to stabilize. This can take as long as 20 minutes- the greater the temperature change, the greater the time. You can use the logging capability of the Kestrel 4000 to confirm that the unit has stabilized to a correct reading: Set the memory options to a relatively short logging interval (20 seconds works well, see page 10 for instructions), select the graphical display of RH, and you can see when the value is no longer changing significantly. At that point, the RH value is stable and can be relied upon to be within the accuracy specifications.

**Barometric Pressure and Altitude Adjustment**

The Kestrel 4000 measures station pressure - the actual air pressure in the measurement location - and uses this value to calculate barometric pressure and altitude. Station pressure changes in response to two things - changes in altitude and changes in the atmosphere. Because the Kestrel 4000 is constantly changing location and altitude, it is important to enter adjustments or "references" when accurate pressure and altitude readings are needed.

Barometric pressure is station pressure corrected to sea level. In order to make the correction, the Kestrel 4000 needs an accurate reference altitude. Altitude is the height above sea level. In order to correctly calculate altitude, the Kestrel 4000 needs an accurate



barometric pressure reference, also known as an "altimeter setting." You only need to know ONE of these values (current barometric pressure or current altitude) in order to set your Kestrel up to show accurate readings.

- *Starting with the known barometric pressure for your location:* You can obtain your current barometric pressure by checking an internet weather site for a nearby location, or contacting a local airport. Set this value as your reference pressure on the ALTITUDE screen to determine your correct altitude: Press the ▬ button to enter the reference setting mode. Press the ▶ button to increase the reference pressure or the ◀ button to decrease the reference pressure. You will notice that the altitude will change with changes in the reference pressure. Press the ▬ button to exit the adjustment mode. Set your Kestrel down on a table and allow the altitude reading to stabilize. (Note: very small changes in pressure generate noticeable changes in altitude. In order to provide meaningful readings for activities where altitude changes quickly, the Kestrel 4000 features rapid altitude response. This is why the altitude readings tend to fluctuate by a few feet.) After obtaining a current altitude from the ALTITUDE screen, move to the BARO screen and enter this value as your reference altitude by following the same procedure. Both readings will now be accurate.


- *Starting with a known altitude for your location:* You can obtain your altitude from a topographical map or local landmark. Set this value as your reference altitude on the BARO screen to determine your barometric pressure: Press the ▬ button to enter the reference setting mode. Press the ▶ button to increase the reference altitude or the ◀ button to decrease the reference altitude. You will notice that the barometric pressure will change with changes in the reference altitude. Press the ▬ button to exit the adjustment mode. Again, allow the Kestrel to stabilize, then enter the value from the BARO screen as your reference pressure on the ALTITUDE screen by following the same procedure. Both readings are now accurate.


When reviewing stored data, remember that changes in pressure AND changes in location/altitude will affect the stored values. When tracking pressure changes relative to weather, set the reference altitude on the BARO screen and keep the Kestrel in one location. Your graph history will now show trends in barometric pressure. Your altitude as shown on the ALTITUDE screen will change as the weather changes, but you can ignore this screen for this purpose.

If you are planning a day hike would like to track your altitude, you'll need to enter the correct reference pressure on the ALTITUDE screen as described above in "starting with the known barometric pressure." You can now track the altitude changes as you hike. In this instance, you should ignore the values on the BARO screen, since the pressure changes will be due to changes in elevation far more than to changes in the weather.

In general, changes in barometric pressure associated with weather changes are small over the course of one day, but they will affect the accuracy of the altimeter over time. This is why aircraft reset their altimeters at every airfield by entering the field's "altimeter setting" or reference pressure. Accordingly, if accurate altitude readings are your primary interest, you should reset the reference pressure on your Kestrel regularly. If you encounter an elevation landmark, you can adjust the reference pressure until the altitude matches the landmark elevation. This will correct the altitude for any pressure changes due to the weather. (Or, you can obtain an updated reference pressure from the sources described above.)

Some final notes - If you wish to know the *actual or station pressure* for your location (such as for engine tuning), simply set the reference altitude on the BARO screen to "0". In this case, the Kestrel will not make any adjustment and will display the measured value. And, the above discussion applies to ALL pressure altimeters, including one you may have in a watch or other device, but not to GPS altimeters

which use satellite triangulation to determine altitude. Note that with present GPS technology, pressure altimeters remain more accurate for measuring altitude change. This is why airplanes still rely on pressure altimeters, not GPS. Finally, the DENSITY ALTITUDE screen is calculated from the absolute values of station pressure, relative humidity and temperature, and is not affected by the reference values entered in the BARO and ALTITUDE screens.

**Manual Data Storage**

To manually store data, press the 📷 button. One of the following will appear: Data Stored (data has been captured and will appear on chart), Full (Overwrite is off and data log is full), or Off (Manual Store button has been disabled). See page 10 for more information on Memory.

**Backlight**

The Kestrel 4000 has a high-visibility green backlight, which makes the display easily read in low-light conditions. The Kestrel 4000 NV has a visible red backlight which preserves the natural night vision of users such as military personnel and pilots. It takes 30 to 45 minutes for the average eye to adapt to darkness and maximize night vision. Even a short burst of white, yellow, green or blue light "bleaches out" the rod cell photoreceptors in the eye and causes night blindness until the entire adaptation process can take place again. Light in the red spectrum does not cause this "bleaching out", preventing night blindness and night vision fatigue. This unit's red backlight is also much dimmer than a standard backlight, making it more difficult to detect with the naked eye in night operations.

Press the ⏻ button to activate the backlight. The light will remain activated for one minute. Press the ⏻ button within one minute to deactivate the light manually.

## Main Setup Menu

You can customize your Kestrel 4000 in multiple ways. Press the ⏻ button to access the Main Setup Menu. Press the — button to select the highlighted setting. The Main Setup Menu contains: OFF, Memory Options, Measurements, Graph Scale, Units, User Screens, System, Date & Time, Language and Restore.

**Off** - Press the ⏻ or the — button to turn the display off. Even when the Kestrel's display is turned off, the unit will continue to automatically store data at the defined Store Rate. Wind speed will NOT be stored when the unit is off. To continuously measure wind speed, turn the auto shutdown off (pg. 11). The battery life will be decreased if data is stored frequently. The only way to completely shut off the unit is to remove the batteries. Custom settings and data will be stored when the batteries are removed.



**Memory Options** - These settings control the data storage properties. Press the ⏻ button to return to the Main Setup Menu.

| Setting | Description | Operation |
|---|---|---|
| **Clear Log** (Go/Done) | All stored data is cleared. This will also clear Min/Max/Avg data. | Press ◀ or ▶ to clear the log. |
| **Reset MMA** (Go/Done) | All Min/Max/Avg data is cleared. Chart data will remain intact. | Press ◀ or ▶ to clear the MMA. |
| **Auto Store** (On/Off) | When On, data is automatically stored at preset Store Rate. When Off, data is only stored when manually captured with the 📷 button. | Press ◀ or ▶ to toggle between On and Off. |
| **Store Rate*** (2 sec - 12 hr) | The frequency at which data sets are automatically stored. (Battery life may be shortened if data is stored frequently.) | Press ◀ or ▶ to increase or decrease Store Rate frequency. |
| **Overwrite** (On/Off) | This setting only applies when the data log is full. When On, oldest data point is discarded to allow memory for the new data point. When Off, new data points are not saved. | Press ◀ or ▶ to toggle between On and Off. |
| **Man Store** (On/Off) | When On, data is stored when the 📷 button is pressed. When off, the 📷 button is disabled. | Press ◀ or ▶ to toggle between On and Off. |

* When unit is off, data is NOT stored for 2 sec and 5 sec Store Rates.

**Measurements** - Measurement screens can be hidden from the normal measurement navigation. For example, if wind chill is not of interest, it can be hidden. Press the ◀ or ▶ button to toggle between ON and OFF for each individual measurement. Press the ▲ or ▼ button to highlight the desired measurement. Press the ⏻ button to return to the Main Setup Menu.

**Graph Scale** - These settings control the chart limits of your meter. Depending on the conditions, the lower and upper limits of the chart scale may need to be adjusted in order to get the best view of the data. Highlight the desired measurement by pressing the ▲ or ▼ button. Select the highlighted measurement by pressing the — button. Press the ◀ or ▶ button to increase or decrease the value of the limits. Press the ▲ or ▼ button to change between the upper and lower limits. Press the ⏻ button to exit and return to the measurement selection screen. Press the ⏻ button to return to the Main Setup Menu.



**Units** - The units of measure can be adjusted to best suit the application. The following units are available:

| Wind Speed | Temperature, Dewpoint, Wet Bulb Temp, Wind Chill & Heat Index | Pressure | Altitude, Density Alt. |
|---|---|---|---|
| m/s meters per second | °C Celsius | inHg inches mercury | m meters |
| km/h kilometers per hour | °F Fahrenheit | hPa hectopascals | ft feet |
| kt knots | | psi pound per square inch | |
| mph miles per hour | | mb millibar | |
| ft/m feet per minute | | | |
| Bft Beaufort | | | |

Highlight the desired measurement by pressing the ▲ or ▼ button. Press the ◀ or ▶ button to scroll through the available units. Press the ⏻ button to return to the Main Setup Menu.

**User Screens** - The three User Screens can be reconfigured to display the most appropriate information for the application. Only current measurements can be selected for the User Screens - Min/Max/Avg and Charts are not available.

Highlight the desired User Screen by pressing the ▲ or ▼ button. Press the — button to select the highlighted User Screen. Press the ▲ and ▼ buttons to change lines, and the ◀ or ▶ button to scroll through the available measurements for each highlighted line. Press the ⏻ button to return to the User Screen Setup Menu. Repeat above process for the other User Screens or press the ⏻ button to return to the Main Setup Menu.

**System** - The display Contrast and Auto Shutdown can be reconfigured as required. The relative humidity and pressure sensors can also be recalibrated. Press the ▲ and ▼ buttons to highlight the appropriate selection, and the ◀ or ▶ button to adjust or select.

The Contrast can be adjusted for better visibility depending on the ambient lighting conditions. Press the ◀ or ▶ button to increase or decrease the contrast from 0 to 20 (0 is lightest, 20 is darkest).

The display can be set to automatically turn off in order to conserve the battery life. Auto Shutdown will only occur after the preset time has elapsed without any button presses. Press the ◀ or ▶ button to scroll through the Auto Shutdown options (15 minutes, 60 minutes, Off).

Baro Cal - The pressure sensor can be calibrated if necessary. It is extremely important to know the precise altitude and mean sea level barometric pressure at the time of calibrating the sensor. First, set the reference altitude on the BARO measurement screen to the known altitude (see Pressure Adjustment on page 9). Then adjust the calibrating setting on the Baro Cal screen to the known mean sea level barometric pressure. Recalibration of this sensor is not typically required, and it is not recommended that you recalibrate without speaking to an NK technician.

Humidity Cal - The humidity sensor can be calibrated by "teaching" it the correct humidity. Some special equipment is required for this calibration, including two hermetically sealed containers and saturated salt solutions. NK offers a calibration kit, and instructions are available on www.nkhome.com. Recalibration of this sensor is not typically required, and it is not recommended that you recalibrate without speaking to an NK technician.

Press the ⏻ button to return to the Main Setup Menu.



**Date & Time** - The date and time, as well as date and time formats, can be adjusted. The Time Formats available are: 12 hour and 24 hour. The Date formats available are day/month/year and month/day/year. (See page 5 for instructions on how to set the date and time.) Press the ⏻ button to return to the Main Setup Menu.

**Language** - Displayed text can be set in one of five languages: English, French, German, Italian or Spanish. To choose a language, use the ▲ and ▼ buttons to highlight the desired language. Press the — button to select the language and return to the Main Setup Menu. Otherwise, press the ⏻ button to return to the Main Setup Menu without changing languages.

**Restore** - Default settings for units of measure, date and time formats, and system settings can be restored. (See page 15 for a list of the default settings.) Press the ▲ or ▼ button to highlight the desired default setting: Metric, Imperial or Defaults. Press the ◀ or ▶ button to reset the factory setting. Press the ⏻ to return to the Main Setup Menu.

## Application Examples

This section provides examples of applications where a Kestrel 4000 might be used, and the appropriate memory settings.

**Weather Monitoring**
Auto Store On
Store Rate 1 hr
Overwrite On
Man Store Off

These settings will allow you to track conditions for almost 3 months. When the memory is full, each new measurement will be stored in place of the oldest data point. The charts will provide a quick look at the recent weather conditions. Keep an eye out for falling barometric pressure, which indicates a storm is coming.

**Hiking/Camping for the Weekend**
Auto Store On
Store Rate 20 min
Overwrite Off
Man Store On

These settings will allow you to track the conditions for almost 26 days. Measurements will be stored every 20 minutes, and stop storing when the log is full. This will let you review the trip at your convenience when you return. You can also manually store the conditions, in case you get caught in 40 mile per hour winds or make it to the top of a mountain. For more detailed information on your trip, set the Store Rate to 2 hours overnight, and 10 minutes during the day.

**Soaring/Hang Gliding**
Auto Store On
Store Rate 2 min
Overwrite Off
Man Store On

These settings will allow you to track all conditions for 66 hours. Chart your altitude changes, watch how the temperature and humidity vary with altitude, and log your apparent speed. Data will no longer be stored once the log is full, in order to preserve it until it can be reviewed later. Be sure to clear the data log just before your flight.

**Skydiving**
Auto Store On
Store Rate 2 sec
Overwrite Off
Man Store Off

These settings will allow you to record a detailed account of your jump. Be sure to clear the data log just before jumping. As you descend toward the ground, you will be tracking the altitude every two seconds, as well as the conditions at that altitude. The chart will clearly show the point at which the parachute opens, as well as the point you get back on the ground.

**HVAC - Environmental Monitoring**
Auto Store On
Store Rate 5 min
Overwrite On
Man Store Off

These settings will record conditions every five minutes, for a total storage of almost 2 days. You can monitor the conditions in a laboratory or manufacturing plant, both day and night, to determine if the climate control is working properly. Or you can examine the effect on the environment when employees enter and exit the building.

**HVAC/R - System Balancing**
Auto Store Off
Store Rate —
Overwrite Off
Man Store On

These settings will require you to press the Manual Store Button in order to store any data at a duct, hood, vent, or other air system. The meter will not store any data automatically. Be sure to record the location and date/time of storage for reference when reviewing the data. After storing the conditions at each location, simply review the data and balance the system.

## Memory Capabilities

| Store Rate | Total Memory | Store Rate | Total Memory |
|---|---|---|---|
| 2 sec | 1 hr, 6 min, 40 sec | 10 min | 13 days, 21 hr, 20 min |
| 5 sec | 2 hr, 46 min, 40 sec | 20 min | 27 days, 18 hr, 40 min |
| 10 sec | 5 hr, 33 min, 20 sec | 30 min | 41 days, 16 hr |
| 20 sec | 11 hr, 6 min, 40 sec | 1 hr | 83 days, 8 hr |
| 30 sec | 16 hr, 30 min | 2 hr | 166 days, 16 hr |
| 1 min | 1 day, 9 hr, 20 min | 5 hr | 416 days, 16 hr |
| 2 min | 2 days, 18 hr, 40 min | 12 hr | 1000 days |
| 5 min | 6 days, 22 hr, 40 min | | |



## Glossary

The below definitions have been greatly simplified in order to keep this section brief. We strongly recommend that anyone who wishes to make use of these measurements refer to one of the many excellent weather references available for a more in-depth definition. On the internet, visit www.usatoday.com or www.noaa.gov. Or, locate the USA Today publication, *The Weather Book*. Please note that any words in a definition printed in *italics* are themselves defined in this glossary.

**Altimeter Setting:** An aviation term for the local barometric pressure. Same as reference pressure.

**Altitude:** The distance above sea level. The Kestrel 4000 calculates altitude based on the measured *station pressure* and the input *barometric pressure* - or "reference pressure".

**Barometric Pressure:** The air pressure of your location reduced to sea level. Pressure will change as weather systems move into your location. Falling pressure indicates the arrival of a low pressure system and expected precipitation or storm conditions. Steady or rising pressure indicates clear weather. A correct altitude must be input for the Kestrel 4000 to display barometric pressure correctly.

**Density Altitude:** The *altitude* at which you would be, given the current air density. Often used by pilots in order to determine how an aircraft will perform. Also of interest to individuals who tune high performance internal combustion engines, such as race care engines.

**Dewpoint:** The *temperature* to which air must be cooled in order for condensation to occur. The difference between *dewpoint* and *temperature* is referred to as the "temperature/dew point spread". A low dewpoint spread indicates high *relative humidity*, while a large dewpoint spread indicates dry conditions.

**Heat Index:** A practical measure of how hot the current combination of *relative humidity* and *temperature* feels to a human body. Higher *relative humidity* makes it seem hotter because our ability to cool ourselves by evaporating perspiration is reduced.

**Reference Pressure:** The local barometric pressure. Input to the altitude screen to provide correct altitude readings. Also known as the altimeter setting.

**Relative Humidity:** The amount of water vapor actually in the air divided by the maximum amount of water vapor the air could hold at that *temperature*, expressed as a percentage.

**Station Pressure:** The *air pressure* of your location, NOT reduced to the sea level equivalent.

**Temperature:** The ambient air temperature.

**Wet Bulb Temperature:** The lowest *temperature* to which a thermometer can be cooled by evaporating water into the air at constant pressure. This measurement is a holdover from the use of an instrument called a sling psychrometer. To measure wet bulb temperature with a sling psychrometer, a thermometer with a wet cloth covering over the bulb is spun rapidly through the air. If the relative humidity is high, there will be little evaporative cooling and the wet bulb temperature will be quite close to the ambient temperature. Some exercise physiology guides use *wet bulb temperature*, rather than *heat index*, as a measure of the safety of exercise in hot and humid conditions.

**Wind Chill:** The cooling effect of combining wind and temperature. The wind chill gives a more accurate reading of how cold it really feels to the human body. The Kestrel 4000's wind chill is based on the National Weather Service standards as of November 1, 2001.



## Default Settings

| UNIT | METRIC | IMPERIAL |
|---|---|---|
| Wind Functions | m/s | mph |
| Temperature Functions | °C | °F |
| Barometric Pressure | hPa | inHg |
| Altitude Functions | m | ft |
| Time Format | 24 hour | 12 hour |
| Date Format | day/month/year | month/day/year |

| SETTING | FACTORY DEFAULT |
|---|---|
| Automatic Data Store | On |
| Data Store Rate | 1 hour |
| Data Overwrite | On |
| Manual Data Store | On |
| User Screen 1 | wind speed, temperature, humidity |
| User Screen 2 | humidity, dewpoint, wet bulb |
| User Screen 3 | pressure, altitude, density altitude |
| Display Contrast | 10 |
| Automatic Shutdown | 15 minutes |
| Language | English |

## PC Upload

Stored data may be uploaded to a PC with the optional Kestrel PC Interface, NK part number 0830.



## Specifications

| Measurement / *Response Time* | Units | Operational Range | Resolution | Accuracy (+/-) | Specification Range |
|---|---|---|---|---|---|
| **Wind Speed** *1 second* | MPH | 0.8 to 135.0 | 0.1 | 3% of reading | 0.8 to 89.0 MPH |
| | fpm | 59 to 11,948 | 1 | | 59 to 7877 |
| | Knots | 0.6 to 118.3 | 0.1 | | 0.6 to 78 |
| | Beaufort | 0 to 12 | 1 | | 0 to 12 |
| | m/s | 0.4 to 60.0 | 0.1 | | 0.4 to 40.0 m/s |
| | KPH | 1.0 | 0.1 | | 1.0 to 144 |

1 inch diameter impeller with precision axle and sapphire bearings, individually tested in NIST-traceable wind tunnel. Calibration drift < 1% after 100 hours use at 16 MPH / 7 m/s. Sustained operation above 60 MPH / 27 m/s will wear impeller rapidly and may cause destruction of impeller. Replacement impeller, PN-0801, may be field-installed without tools (US Patent 5,783,753).

| Measurement / *Response Time* | Units | Operational Range | Resolution | Accuracy (+/-) | Specification Range |
|---|---|---|---|---|---|
| **Temperature** *1 minute* | °F | -50.0 to 260.0 | 0.1 | 1.8 | -20 to 158 |
| | °C | -45.0 to 125.0 | 0.1 | 1 | -29 to 70 °C |

Thermally isolated, hermetically sealed, precision thermistor mounted externally (US Patent 5,939,645). Calibration drift negligible.

| Measurement / *Response Time* | Units | Operational Range | Resolution | Accuracy (+/-) | Specification Range |
|---|---|---|---|---|---|
| **Relative Humidity** *1 minute* | %RH | 0.0 to 100.0 | 0.1 | 3.0 %RH | 5 to 95 % non |

Polymer capacitive humidity sensor mounted in thin walled chamber external to case for rapid, accurate response (US Patent 6,257,074). Response specification is time to achieve 95% or better of stated accuracy. Calibration drift +/- 2% over 24 months. Relative humidity may be recalibrated at factory or in field using Kestrel Humidity Calibration Kit, PN-0824.

| Measurement / *Response Time* | Units | Operational Range | Resolution | Accuracy (+/-) | Specification Range |
|---|---|---|---|---|---|
| **Pressure** *1 second* | inHg | 8.86 to 32.48 | 0.01 | 0.05 | At 77°F, <19,700 ft |
| | hPa | 300.0 to 1100.0 | 0.1 | 1.5 | At 25 °C, <6,000 m |
| | millibars | 300.0 to 1100.0 | 0.1 | 1.5 | At 25 °C, <6,000 m |

Monolithic silicon piezoresistive pressure sensor with second order temperature correction. Maximum error beyond specified temperature, +/- 0.09 inHg / 3.0 hPa. Calibration drift typically -0.03 inHg / -1.0 hPa per year. Pressure sensor may be recalibrated at factory or in field (facilitated by Kestrel Computer Interface, PN-0830).

| Measurement / *Response Time* | Units | Operational Range | Resolution | Accuracy (+/-) | Specification Range |
|---|---|---|---|---|---|
| **Dewpoint** *1 minute* | °F | 0.0 to 100.0 %RH, -50.0 to 260.0 °F | 0.1 | 3.6 | -20 to 158 °F, 20 to 95% RH |
| | °C | 0.0 to 100.0 %RH, -45.0 to 125.0 °C | 0.1 | 2 | -29 to 70 °C, 20 to 95 %RH |

| Measurement | Units | Operational Range | Resolution | Accuracy (+/-) | Specification Range |
|---|---|---|---|---|---|
| **Heat Index** | °F | 0.0 to 100.0 %RH, -50.0 to 260.0 °F | 0.1 | 3.6 | -20 to 158 °F, 20 to 95% RH |
| *1 minute* | °C | 0.0 to 100.0 %RH, -45.0 to 125.0 °C | 0.1 | 2 | -29 to 70 °C, 20 to 95 %RH |

The above values are calculated from the primary measurements of wind speed, temperature and relative humidity.

| Measurement | Units | Operational Range | Resolution | Accuracy (+/-) | Specification Range |
|---|---|---|---|---|---|
| **Wind Chill** | °F | 0.7 to 135.0 MPH, -50.0 to 260.0 °F | 0.1 | 1.8 | 1.8 to 89 MPH, -20 to 158 °F |
| *1 second* | °C | 0.4 to 60.0 m/s, -45.0 to 125.0 °C | 0.1 | 1 | 0.4 to 40 m/s, -29 to 70 °C |
| **Dewpoint** | °F | 0.0 to 100.0 %RH, -50.0 to 260.0 °F | 0.1 | 3.6 | -20 to 158 °F, 20 to 95% RH |
| *1 minute* | °C | 0.0 to 100.0 %RH, -45.0 to 125.0 °C | 0.1 | 2 | -29 to 70 °C, 20 to 95 %RH |
| **Heat Index** | °F | 0.0 to 100.0 %RH, -50.0 to 260.0 °F | 0.1 | 3.6 | -20 to 158 °F, 20 to 95% RH |
| *1 minute* | °C | 0.0 to 100.0 %RH, -45.0 to 125.0 °C | 0.1 | 2 | -29 to 70 °C, 20 to 95 %RH |
| **Wet Bulb** | °F | -50.0 to 260.0 °F, 0.0 to 100.0 %RH, 8.86 to 32.48 inHg | 0.1 | 3.6 | 32 to 100 °F, 5 to 95% RH, 8.86 to 32.48 inHg, <19700 ft |
| *1 minute* | °C | -45.0 to 125.0 °C, 0.0 to 100.0 %RH, 300.0 | 0.1 | 2 | 0 - 37 °C, 5 to 95 %RH, -2000 to 9000 hPa, <6000 m |
| **Altitude** | ft | -6000 to 30000 ft | 1 | 50 | At 77°F, <19,700 ft, Max error +/- 98 ft |
| *1 second* | m | -2000 to 9000 m | 1 | 15 | At 25 °C, <6,000 m, Max error +/- 30 m |
| **Density Altitude** | ft | -50.0 - 260.0 °F, 0.0 to 100.0 % RH, 8.86 to 32.48 inHg | 1 | 246 | 32 to 100 °F, 5-95% RH, 8.86 to 32.48 inHg, <19700 ft |
| *1 second* | m | -45.0 to 125.0 °C, 0.0 to 100.0 %RH, 300.0 to 1100.0 hPa | 1 | 75 | 0 - 37 °C, 5 to 95 %RH, -2000 to 9000 hPa, <6000 m |

The above values are calculated from the primary measurements of wind speed, temperature, relative humidity and pressure.



| | |
|---|---|
| **Data Display and Storage** | Minimum, maximum, average and logged history stored and displayed for every measured value. 2000-point data logger with graphical display. Auto data storage; interval settable from 2 seconds to 12 hours. Manual data capture. |
| **Display Digits** | Multifunction, multi-digit programmable dot-matrix display. |
| **Display Update** | 1 second |
| **Display Languages** | English, French, German, Italian, Spanish |
| **Display Backlight** | Choice of aviation green or visible red electroluminescent backlight. Automatic or manual operation. |
| **Operational Temperature Range** | The operational temperature range of the liquid crystal display and batteries is 0° F to 131° F / -18 °C to 55 °C. Beyond the limits of this range, the unit must be maintained within range and exposed for minimum time necessary to take reading. |
| **Storage Temperature** | -22 °F to 140 °F / -30 °C to 60 °C |
| **Auto Shutdown** | User-selectable: 15 minutes, 60 minutes or disabled |
| **Batteries** | AAA Alkaline, two, included. Average life, 400 hours of use, +/-depending on backlight use. |
| **Sealing** | Waterproof (IP67 standard) |
| **Dimensions** | 5.0 x 1.8 x 1.1 in / 12.7 x 4.5 x 2.8 cm |
| **Weight** | 3.6 oz / 102 gm |
| **Color** | Dark grey, safety orange or olive drab (FED-STD-595B, Color 34088). |



NK
**Nielsen-Kellerman**
**610.447.1555**
**www.nkhome.com**
**info@nkhome.com**

Instruction Manual for Kestrel 4000 version: 4.10 ALL

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## APPENDIX F. MANUAL_LOGO24_7MB

Manual

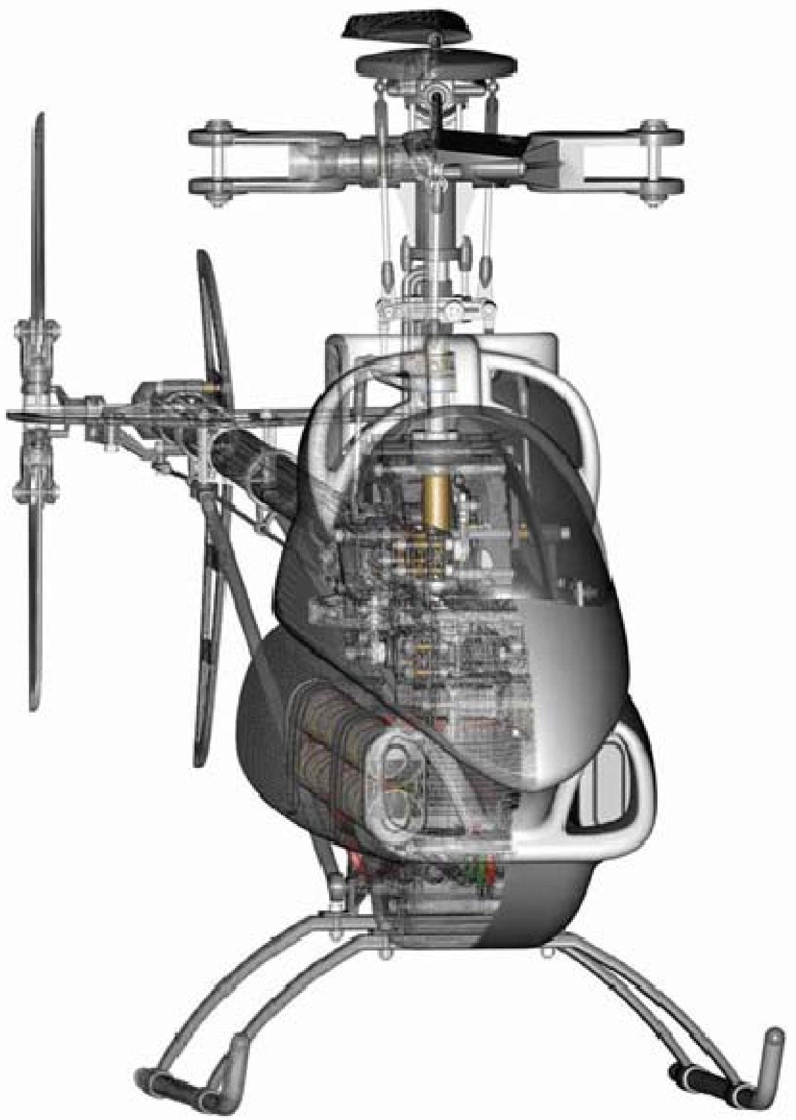
LOGO 24

BIONIC

Mikado

Model Helicopters

www.mikado-heli.de

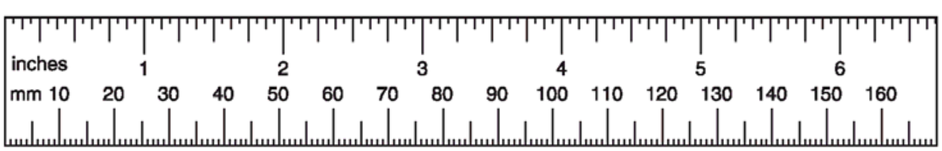


Mikado Modellhubschrauber • Friedrich-Klausing-Straße 2 • 14469 Potsdam • Germany
Phone +49 (0)331 23749-0 • Fax +49 (0)331 23749-11 • www.mikado-heli.de

# Index



**All parts shown in the boxes are displayed in real size.**



## OPERATING YOUR MODEL SAFELY

**Operate the helicopter in spacious areas with no people nearby.**
**!Warning:** Do NOT operate the helicopter in the following places and situations (or else you risk severe accidents):
- in places where children gather or people pass through
- in residential areas and parks
- indoors and in limited space
- in windy weather or when there is any rain, snow, fog or other precipitation

If you do not observe these instructions you may be held reliable for personal injury or property damage!

Always check the R/C system prior to operating your helicopter.
When the R/C system batteries get weaker, the operational range of the R/C system decreases. Note that you may lose control of your model when operating it under such conditions.

Keep in mind that other people around you might also be operating a R/C model.
Never use a frequency which someone else is using at the same time. Radio signals will be mixed and you will lose control of your model.

If the model shows irregular behavior, bring the model to a halt immediately. Turn off all power switches and disconnect the batteries. Investigate the reason and fix the problem. Do not operate the model again as long as the problem is not solved, as this may lead to further trouble and unforeseen accidents.

**!Warning:** In order to prevent accidents and personal injury, be sure to observe the following:
Before flying the helicopter, ensure that all screws are tightened. A single loose screw may cause a major accident.
Replace all broken or defective parts with new ones, as damaged parts lead to crashes.
Never approach a spinning rotor. Keep at least 10 meters/yards away from spinning rotor blades.
Do not touch the motor immediately after use. It may be hot enough to cause burns.
Perform all necessary maintenance.

## PRIOR TO ADJUSTING AND OPERATING YOUR MODEL, OBSERVE THE FOLLOWING

**!Warning:** Operate the helicopter only outdoors and out of people's reach as the main rotor operates at high rpm!
**!Warning:** While adjusting, stand at least 10 meters/yards away from the helicopter!

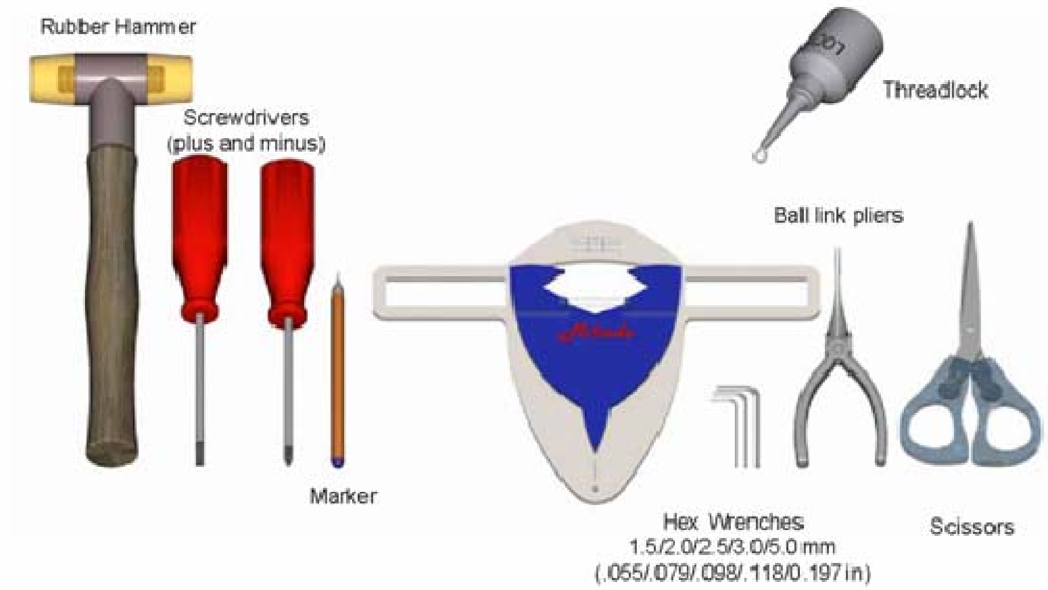
Novice R/C helicopter pilots should always seek advice from experienced pilots to obtain hints with assembly and for pre-flight adjustments. Note that a badly assembled or insufficiently adjusted helicopter is a safety hazard! In the beginning, novice R/C helicopter pilots should always be assisted by an experienced pilot and never fly alone!
Throttle channel should be in motor OFF position while powering up.
When switching the R/C system ON or OFF, always proceed in the following order:

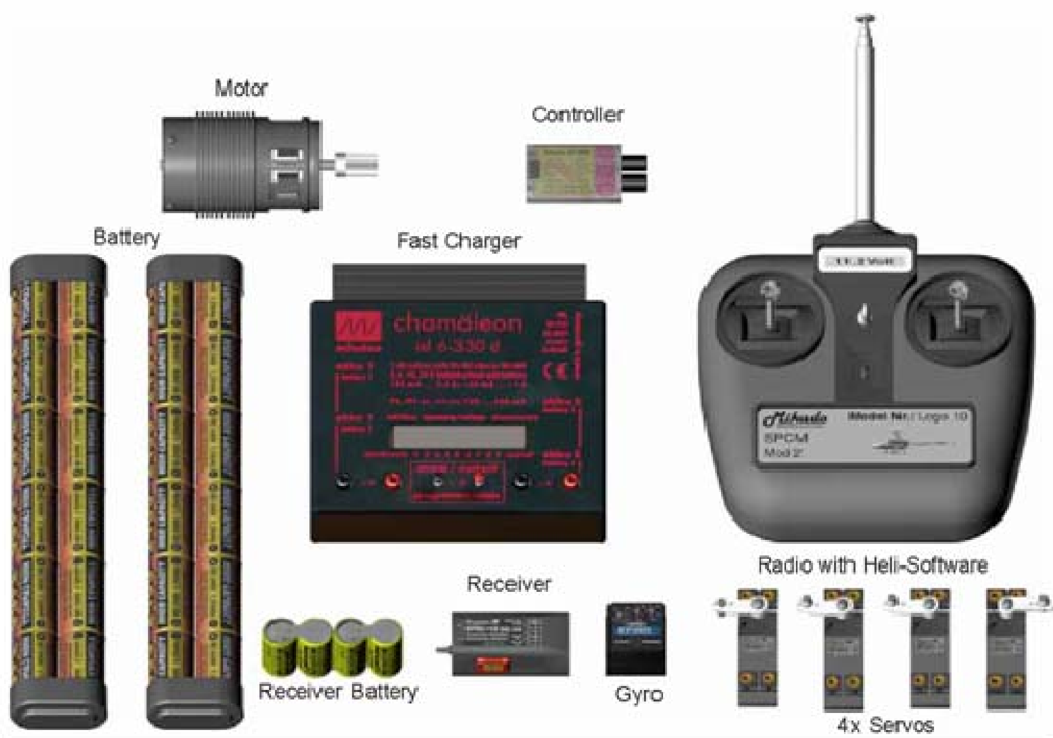
**When switching ON:**
- Position the throttle control stick (on transmitter) to a position where the LOGO 24 motor does not operate.
- Turn on the transmitter.
- Turn on the receiver.
- Connect the motor battery.
- Operate your model.

**When switching OFF:**
- Turn off the motor (move throttle control to a position where motor does not operate).
- Wait until the rotor head has stopped spinning.
- Disconnect the motor battery.
- Turn off receiver.
- Turn off transmitter.

We strongly advise to use the motorsets and R/C components which are recommended by Mikado. If you use different components, the flight properties of the LOGO 24 may be diminished. Other effects can be failure and premature wear of the parts. You will find references to suitable motorsets, pinions and battery packs on Mikado's website www.mikado-heli.de. Do not exceed the recommended rotor head speed of 1600 rpm.

# Tools for Assembly & R/C Equipment

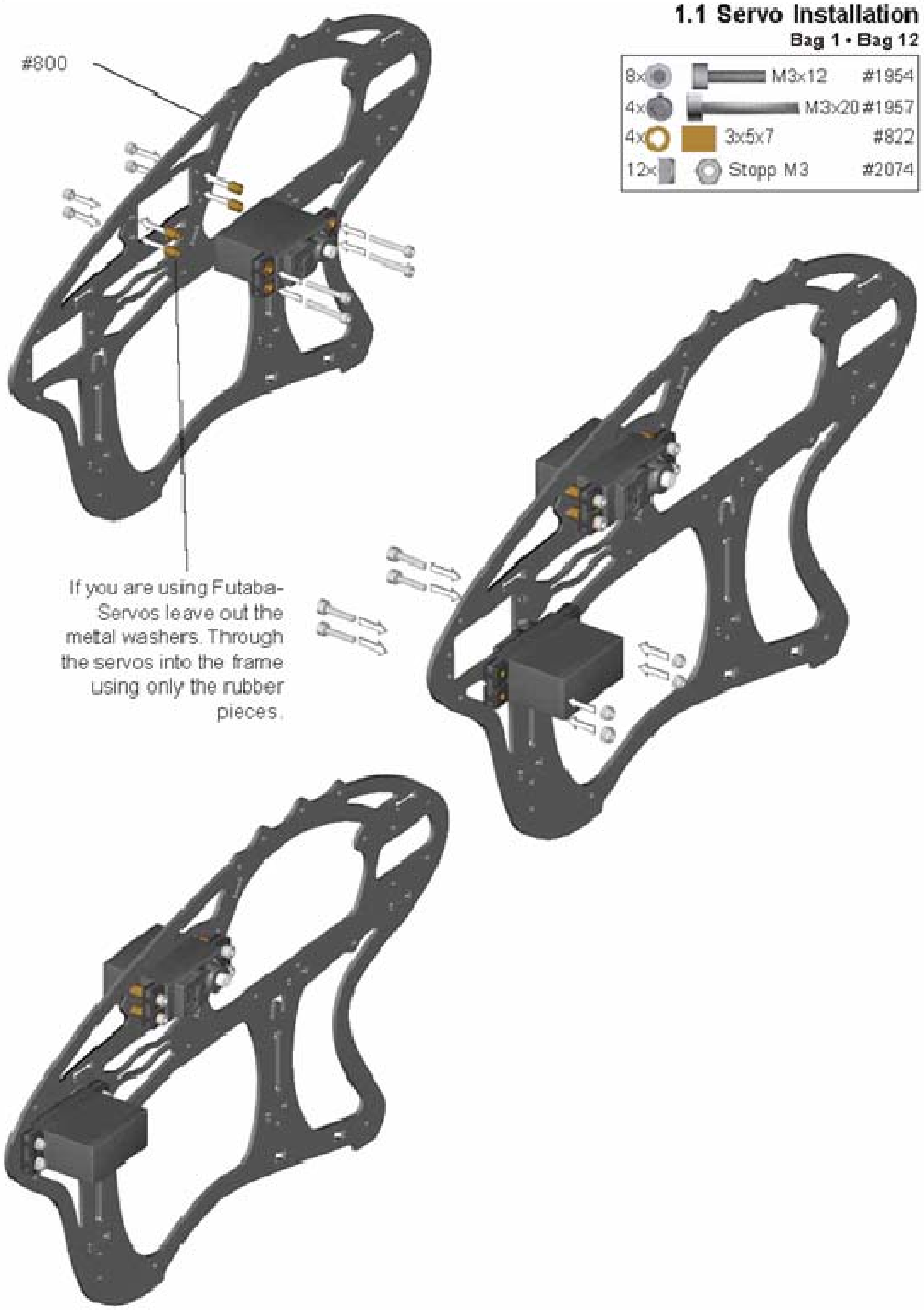


## 1.1 Servo Installation

**Bag 1 • Bag 12**

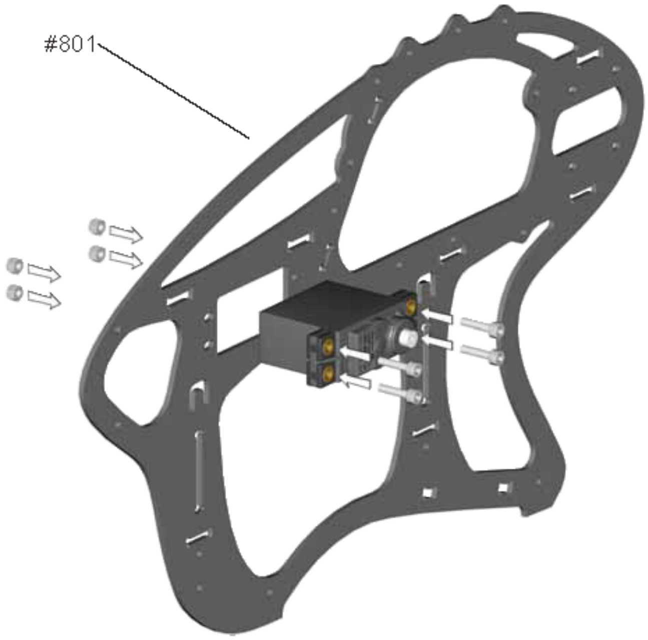
| | | | |
|---|---|---|---|
| 8x | | M3x12 | #1954 |
| 4x | | M3x20 | #1957 |
| 4x | | 3x5x7 | #822 |
| 12x | | Stopp M3 | #2074 |




If you are using Futaba-Servos leave out the metal washers. Through the servos into the frame using only the rubber pieces.

# 1 Main Frame

## 1.1 Servo Installation

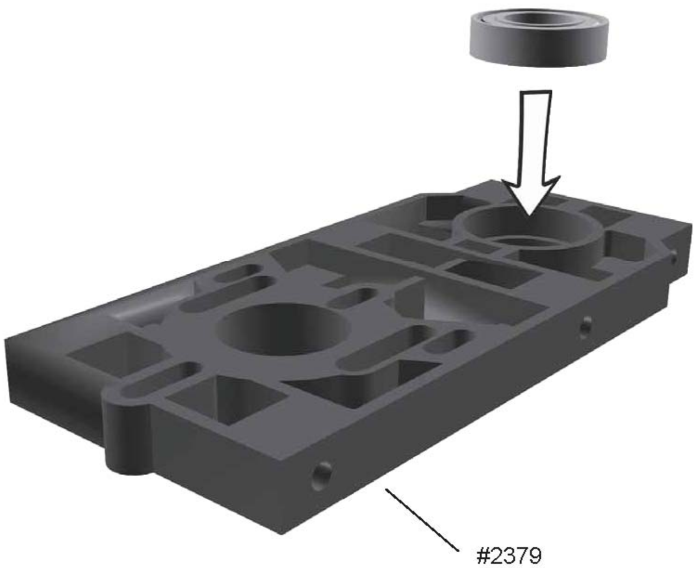



# 1 Main Frame

## 1.2 Motor Plate

**Bag 1 • Bag 10**

| | | | |
|---|---|---|---|
| 1x | | 10x19x5 | #1329 |
| 6x | | M3 | #2072 |

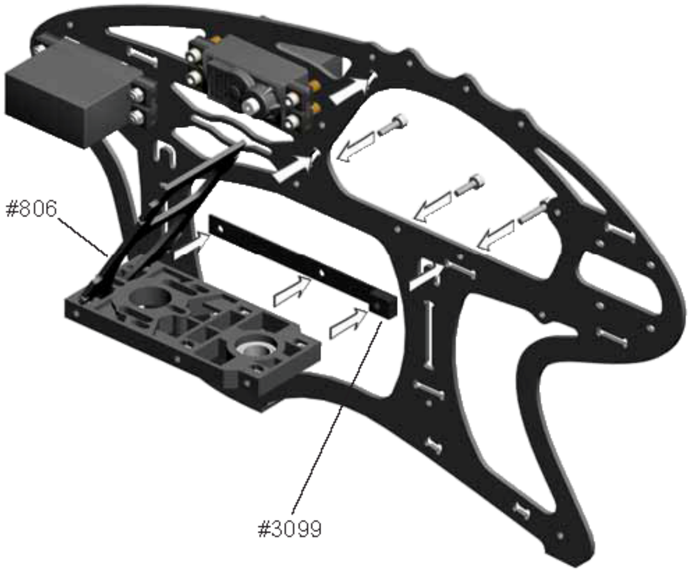



# 1 Main Frame

## 1.2 Motor Plate

**Bag 1 • Bag 12**

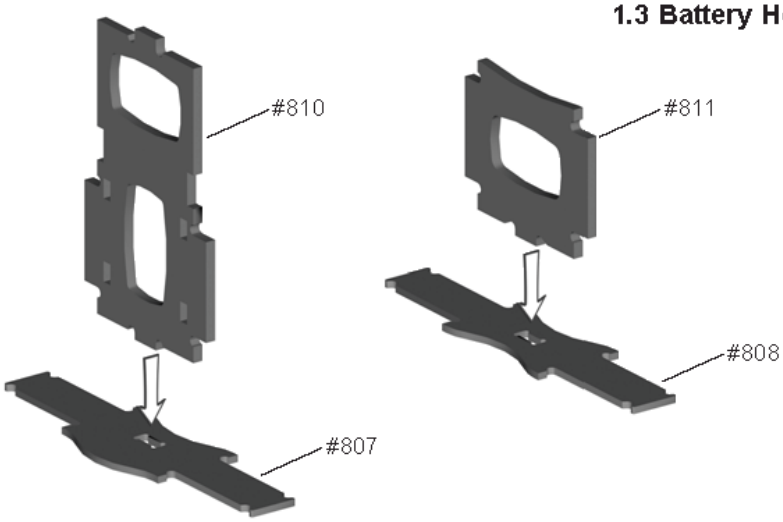
| | | | |
|---|---|---|---|
| 2x | | M3x10 | #1953 |
| 1x | | M3x14 | #1955 |



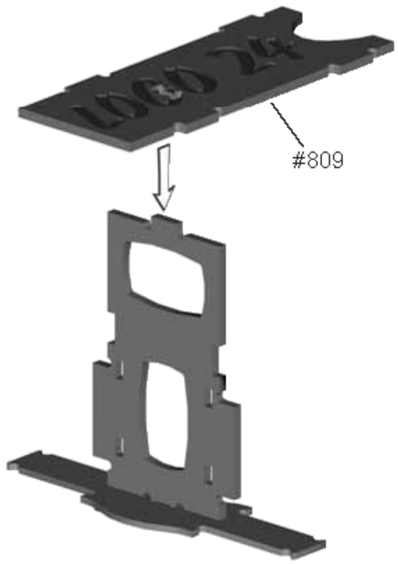

**Note:** Because the individual parts of the chassis must fit very tightly together, they may be slightly difficult to assemble. The reason is that the finished chassis of LOGO 24 will be very rigid for optimal flying properties. Where necessary, please remove a small amount of excess material at the edges of braces #807 to #811 with a file or a sharp knife.

## 1.3 Battery Holder and R/C Plate

**Bag 1**

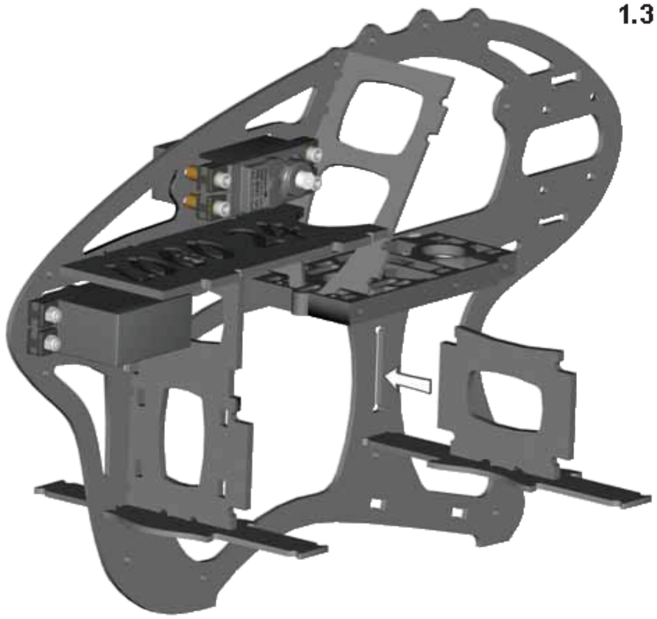


## 1.3 Battery Holder and R/C Plate



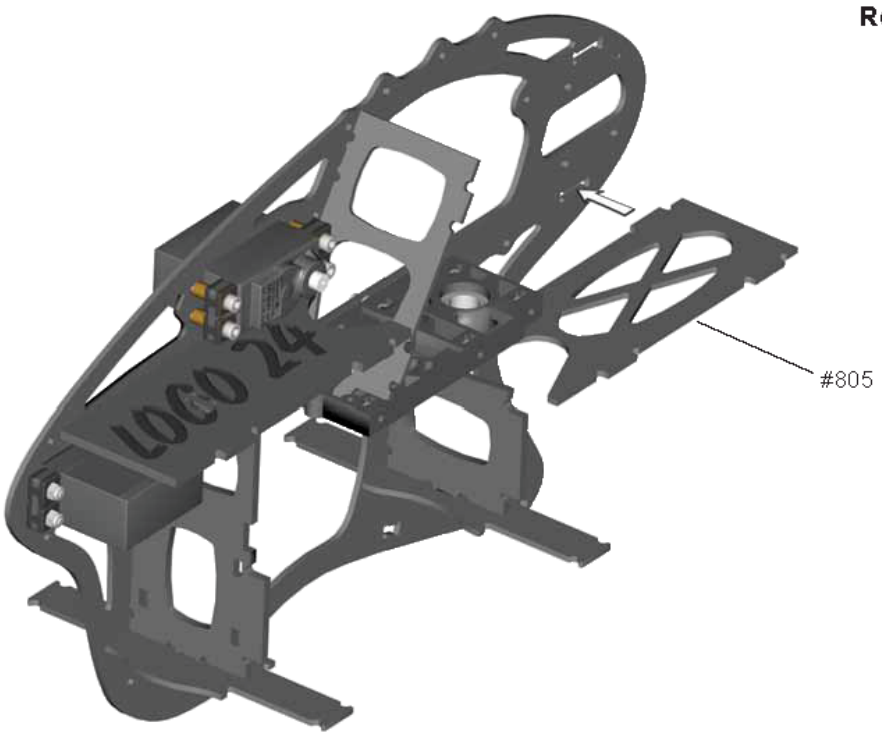

## 1.3 Battery Holder and R/C Plate

**Bag 1**



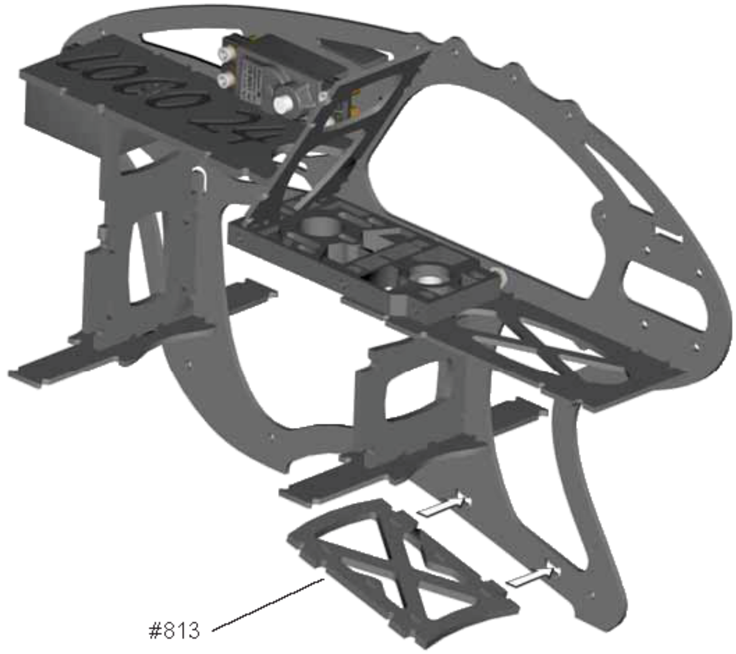
## Rear Brace

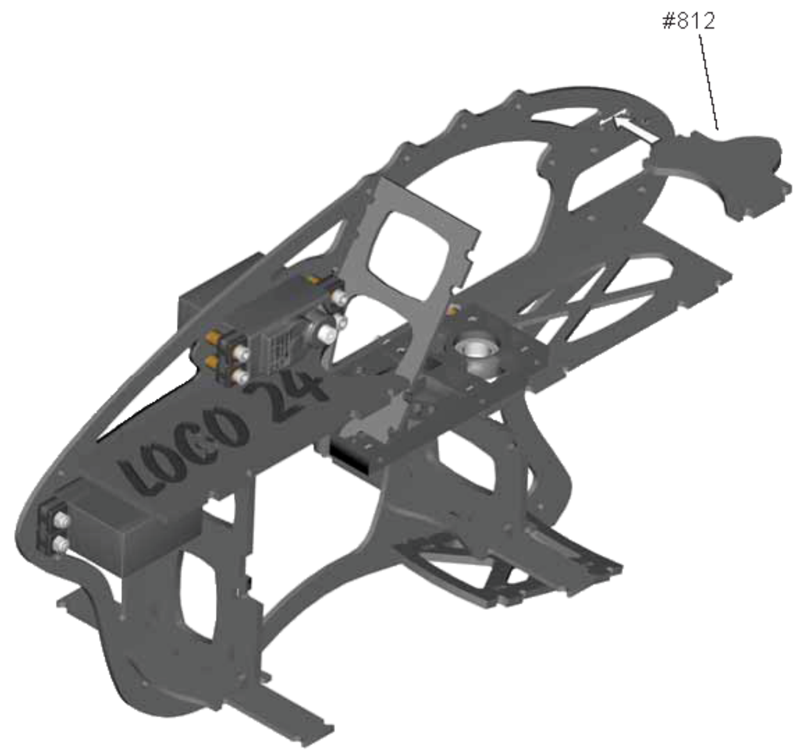
**Bag 1**



## 1.4 Controller Plate and Gyro Plate

**Bag 1**

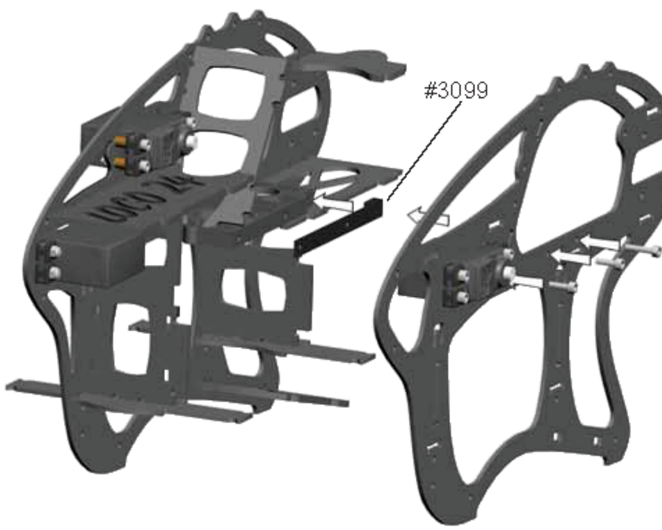


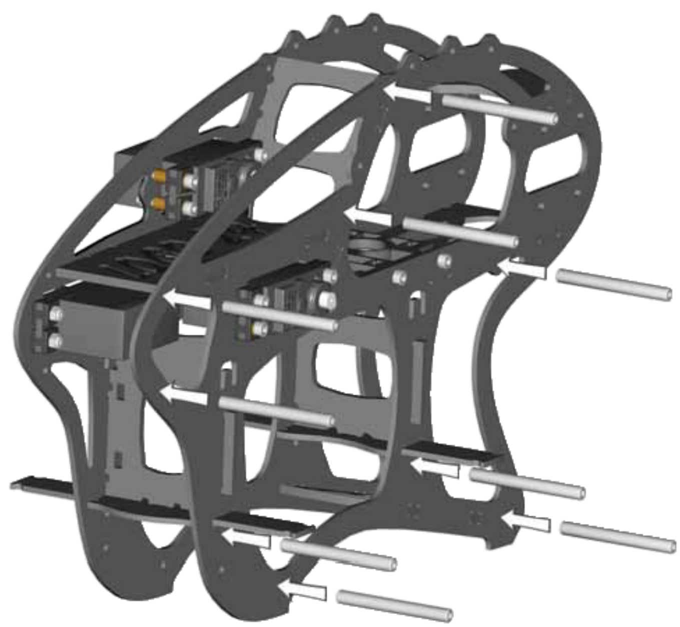



## 1.5 Chassis Assembly

**Bag 1 • Bag 12**

| | | | |
|---|---|---|---|
| 2x | | M3x10 | #1953 |
| 1x | | M3x14 | #1955 |
| 9x | | 45,5mm | #816 |

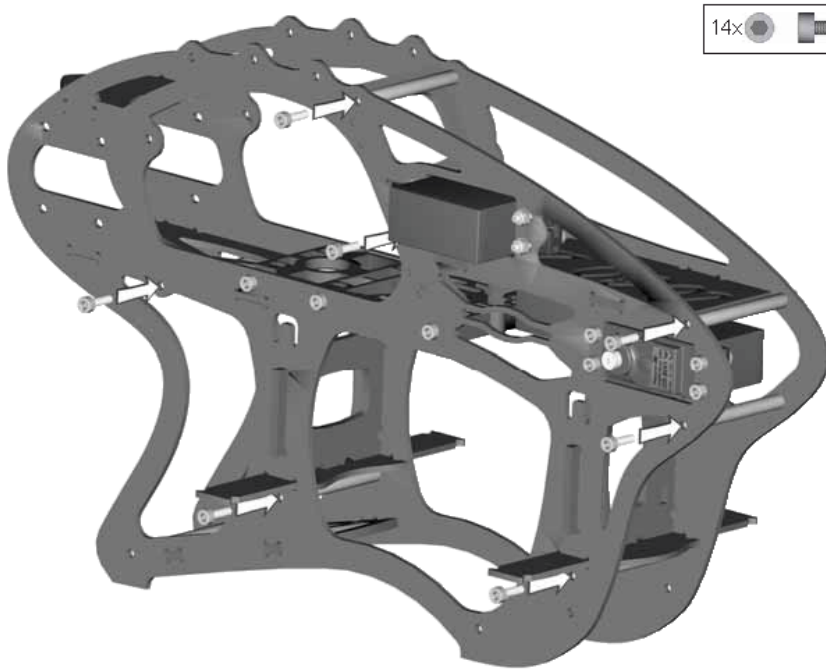


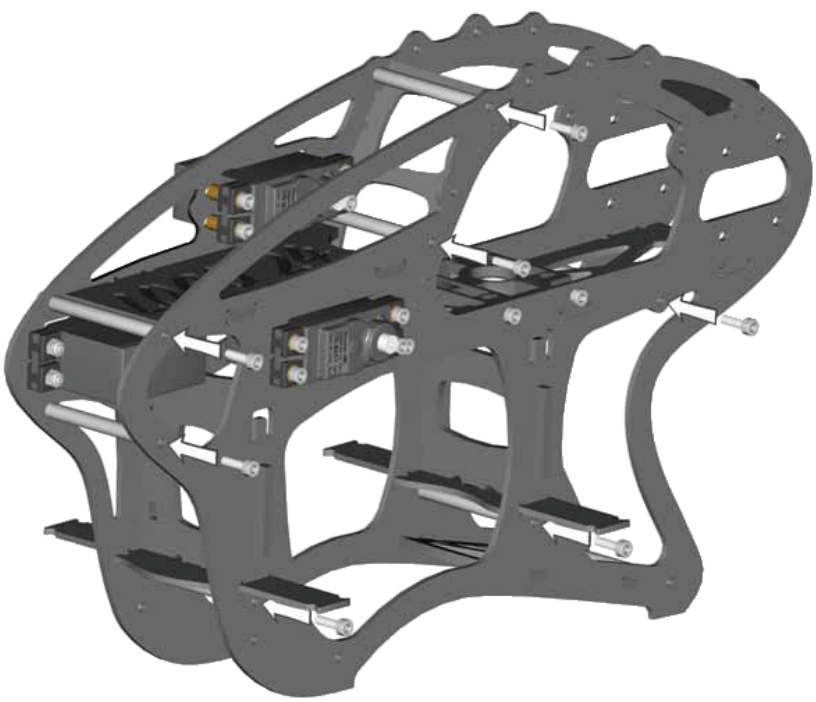



## 1.6 Final Chassis Assembly

**Bag 12**

| | | | |
|---|---|---|---|
| 14x | | M3x10 | #1953 |



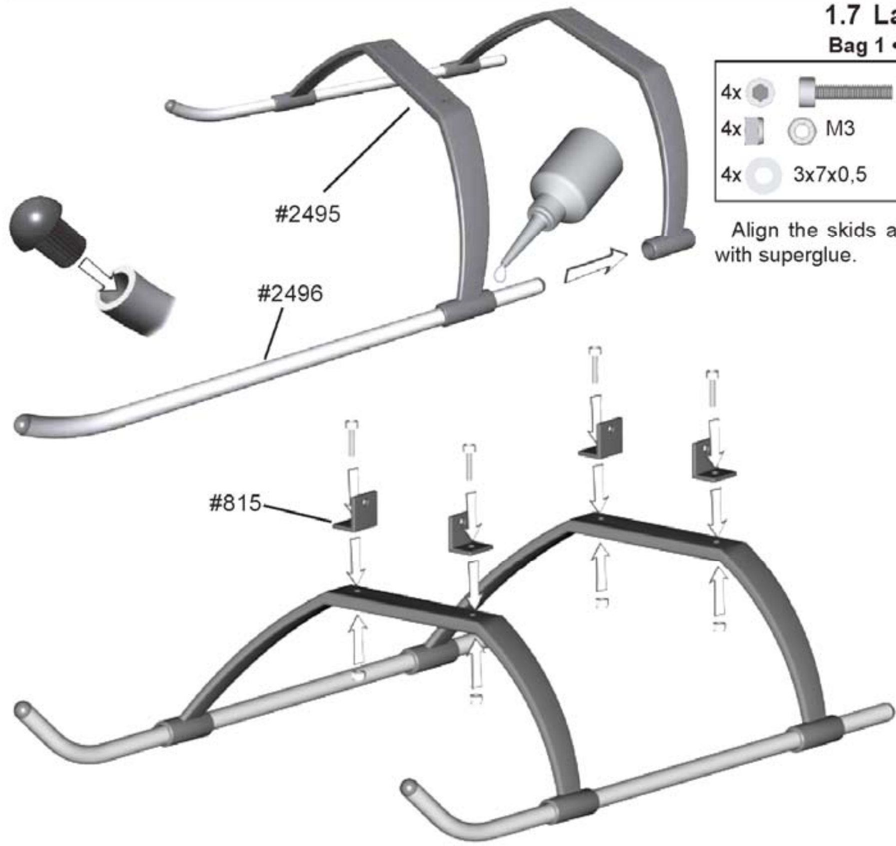


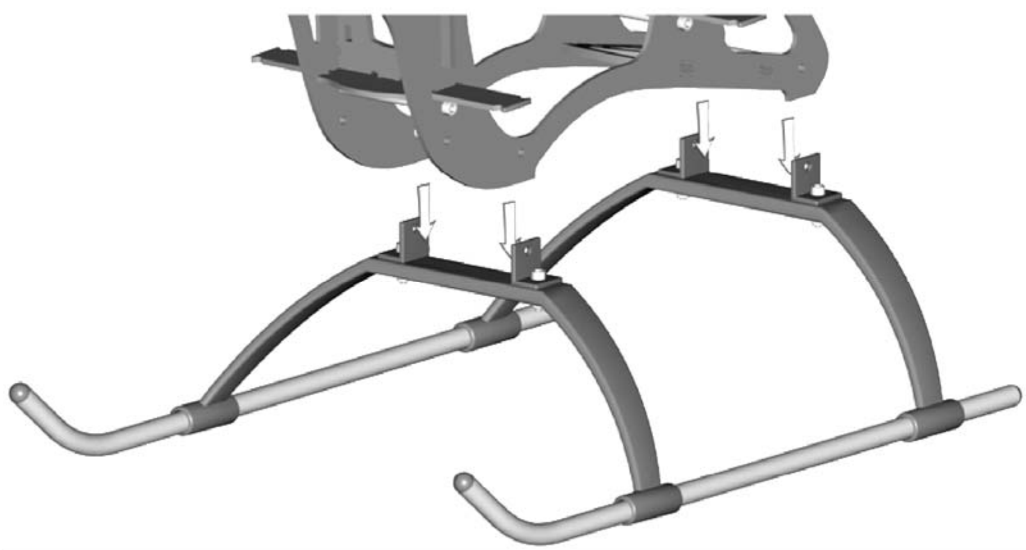
## 1.7 Landing Gear

**Bag 1 • Bag 8 • Bag 12**

| | | | |
|---|---|---|---|
| 4x | | M3x14 | #1955 |
| 4x | | M3 | #2074 |
| 4x | | 3x7x0,5 | #2012 |

Align the skids and secure them with superglue.



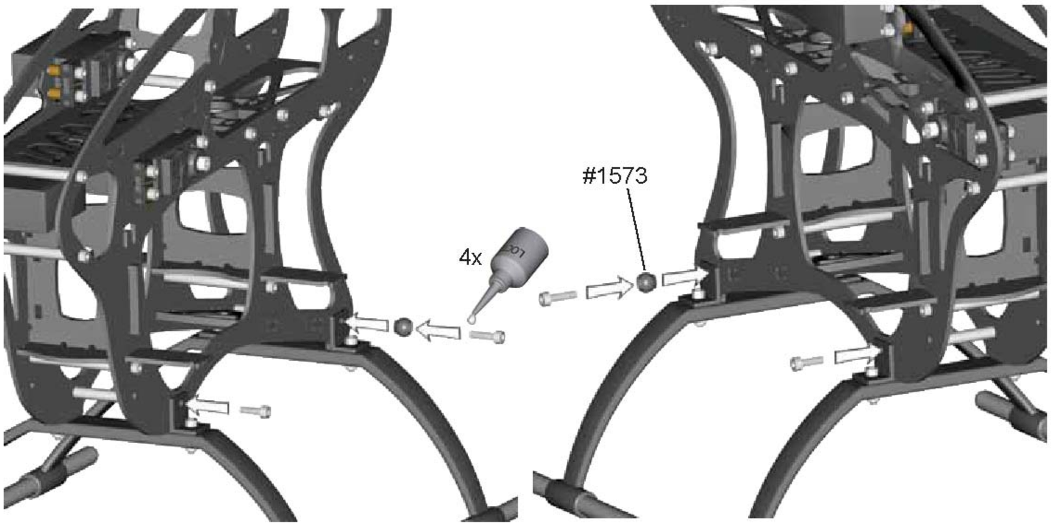



# 1 Main Frame

## 1.7 Landing Gear

**Bag 1 • Bag 12**

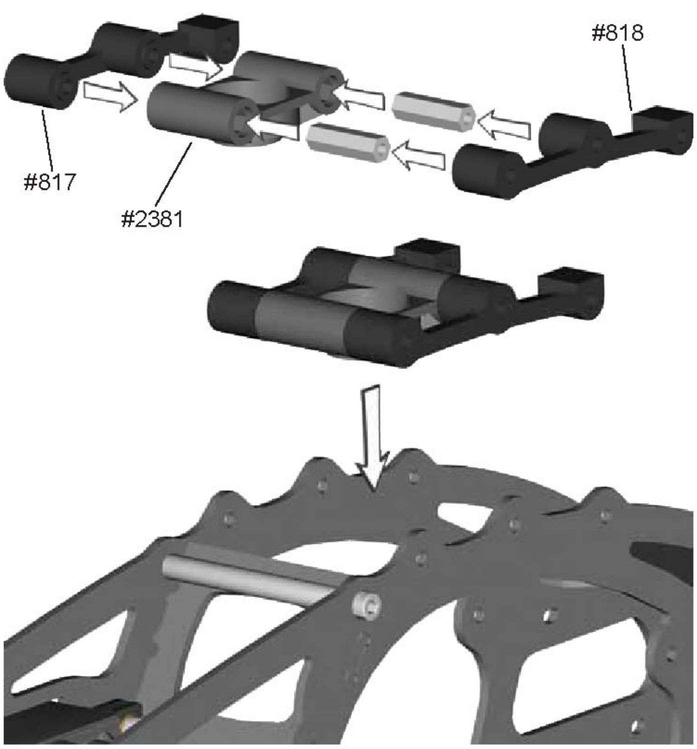
4x M3x12 #1954




## 1.8 Bearing Case

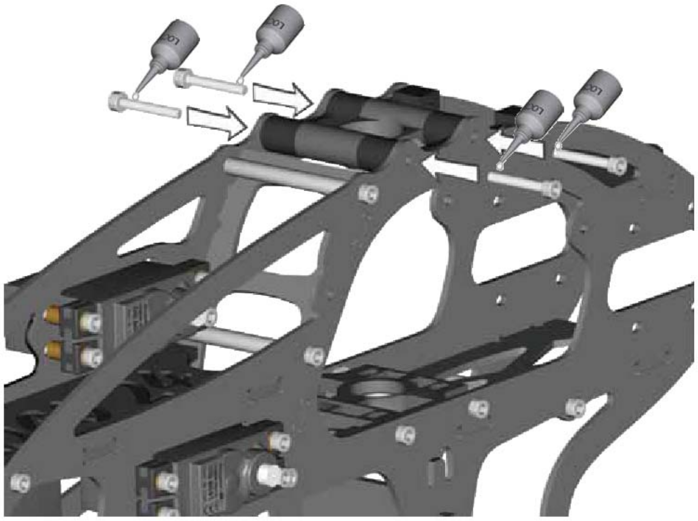
**Bag 1 • Bag 10 • Bag 12**

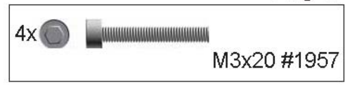
2x 19mm #2372



## 1.8 Bearing Case

Bag 12



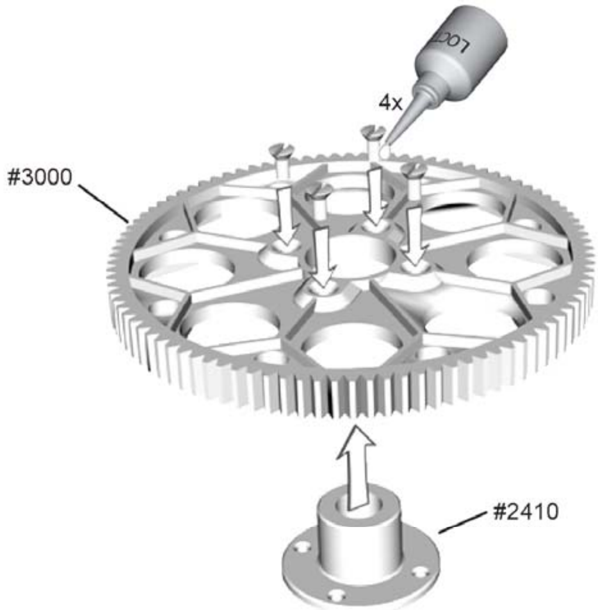


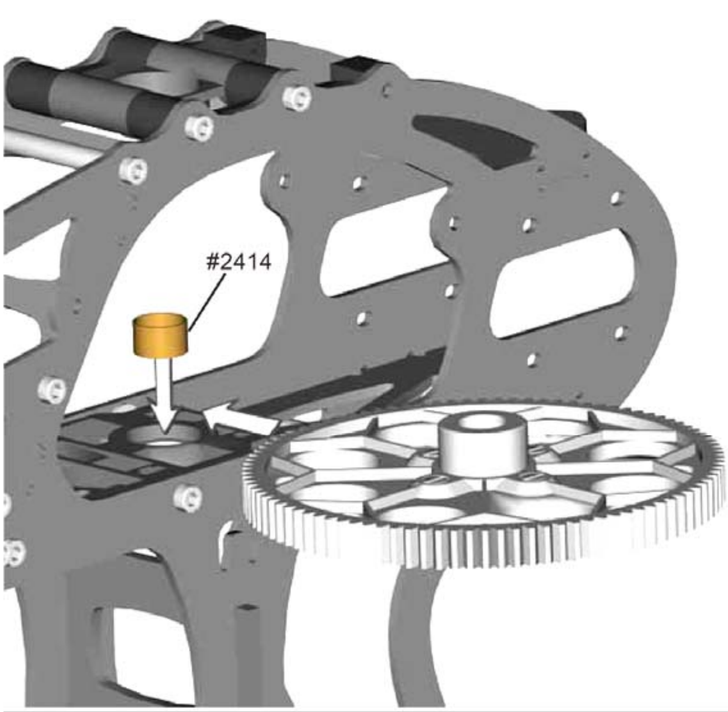

# 1 Main Frame

## 1.9 Main Gear

**Bag 2**

| | | | |
|---|---|---|---|
| 4x | | M3x8 | #1915 |



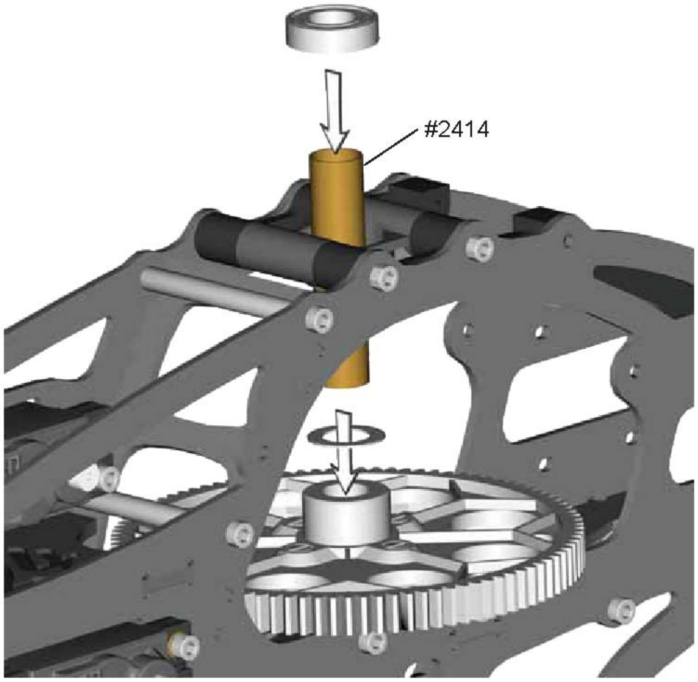



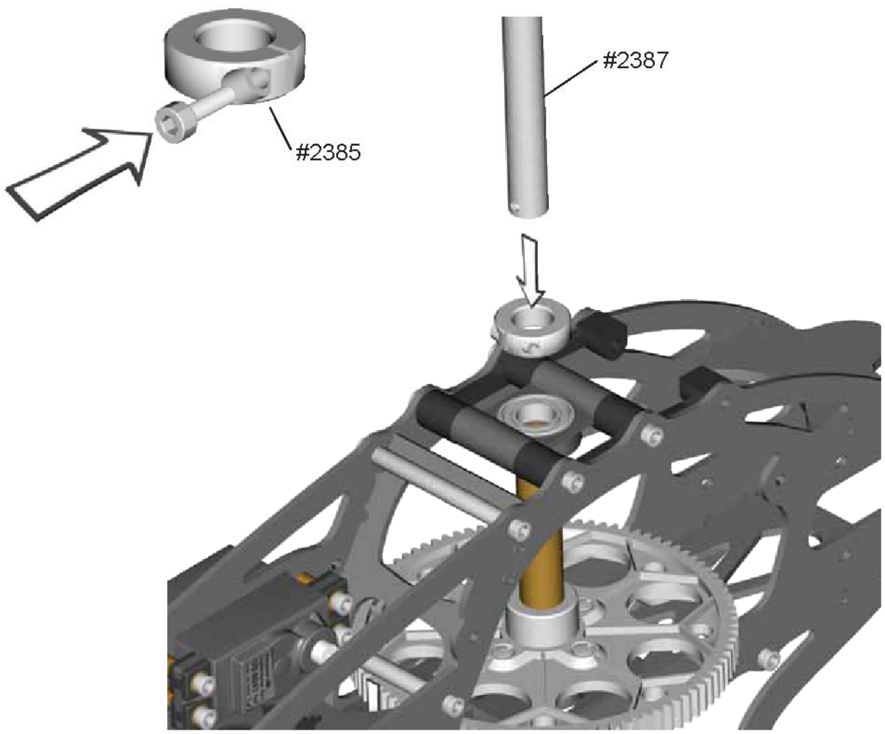
## 1.10 Main Rotor Shaft

**Bag 2 • Bag 10 • Bag 12**

| | | | |
|---|---|---|---|
| 1x | | M2,5x8 | #1940 |
| 1x | | 10x19x5 | #1329 |
| 1x | | 10x16x0,5 | #2010 |
| 1x | | 10x16x0,2 | #2009 |

If the main gear shows axial play on the main rotor shaft, please use washer #2009 in addition to washer #2010.

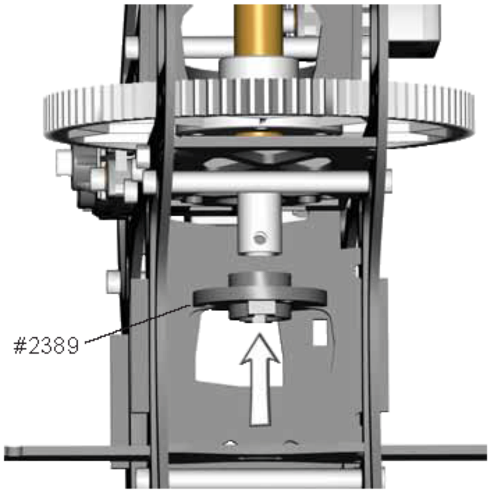


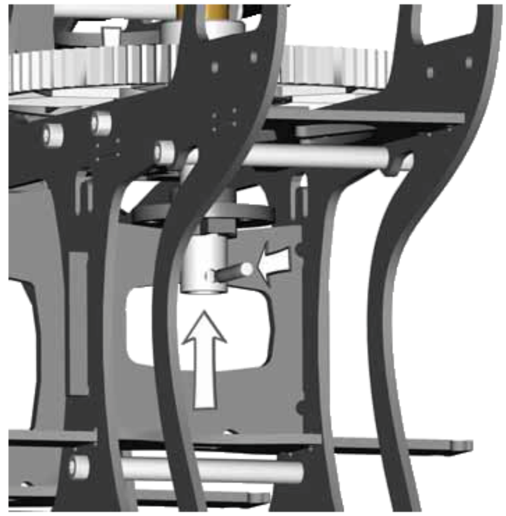



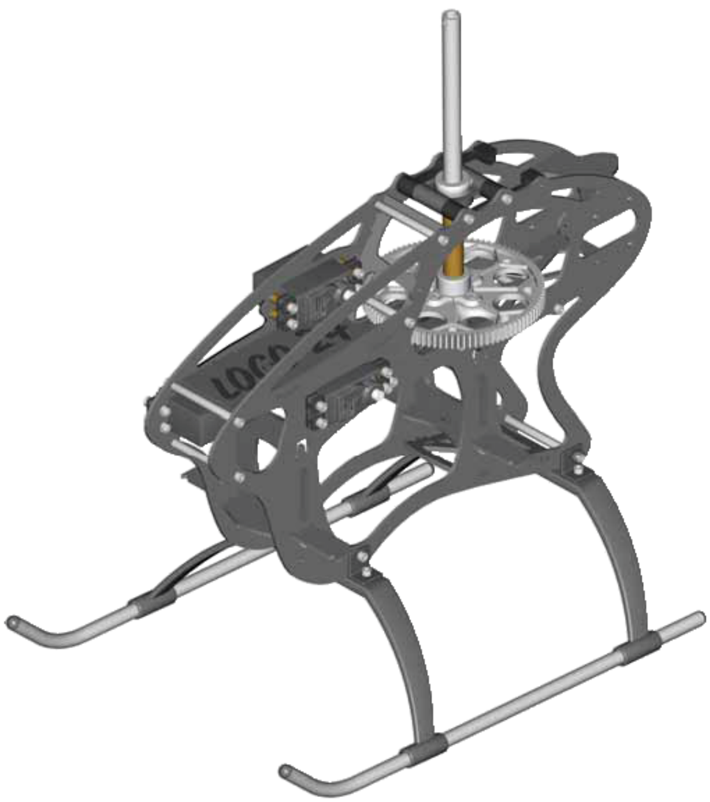
## 1.10 Main Rotor Shaft

**Bag 2 • Bag 12**

| | | | |
|---|---|---|---|
| 1x | | 3x18 | #2388 |



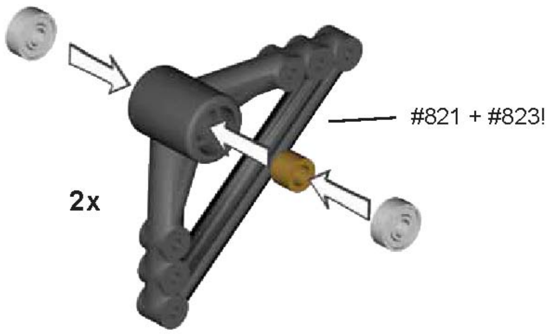


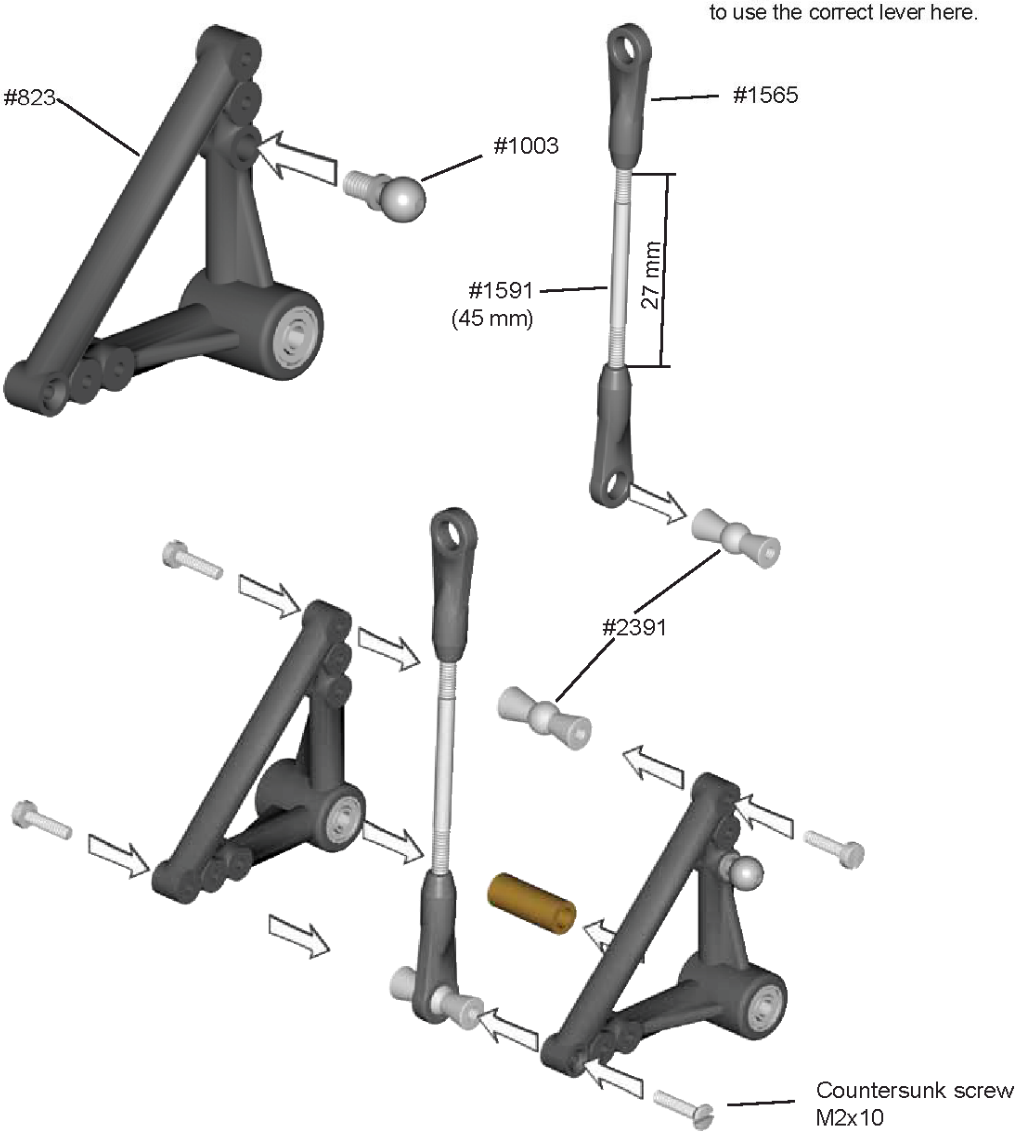
## 1.11 Elevator Lever

**Bag 4 • Bag 10 • Bag 12**

| | | |
|---|---|---|
| 4x | 3x7x3 | #930 |
| 2x | 3x5x7 | #822 |
| 3x | M2x8 | #1902 |
| 1x | 3x4x12 | #3032 |
| 1x | M2x10 | #1911 |

**Note:** The elevator lever #823 is different from the other three. For instance, it has special holes for attaching part #1003 and #1911. Be sure to use the correct lever here.



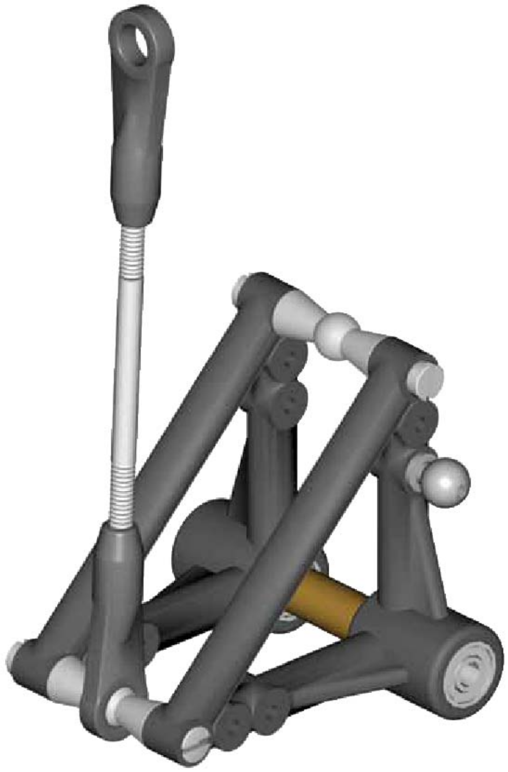



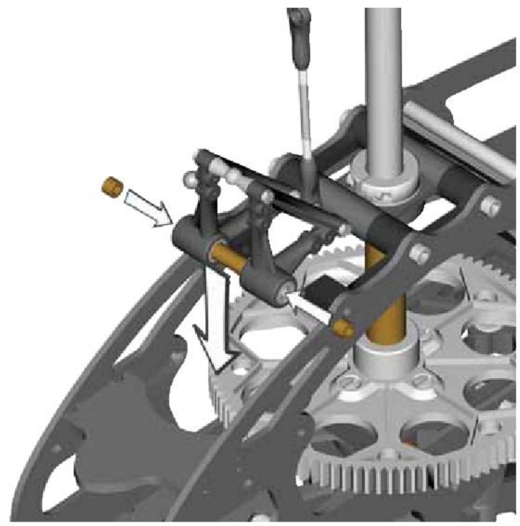
# 1 Main Frame

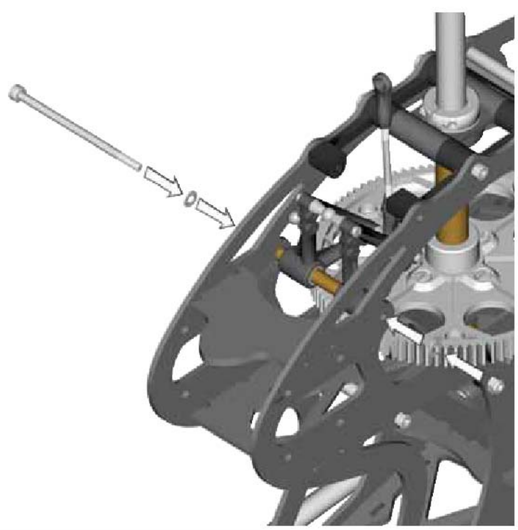
## 1.11 Elevator Lever

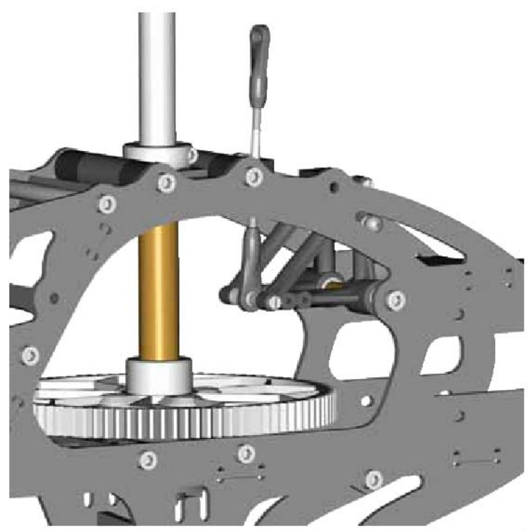
**Bag 4 • Bag 12**

| | | | |
|---|---|---|---|
| 1x | | M3x55 | #1963 |
| 1x | | Stopp M3 | #2074 |
| 2x | | 3x5x4 | #924 |
| 2x | | 3x7x0,5 | #2012 |





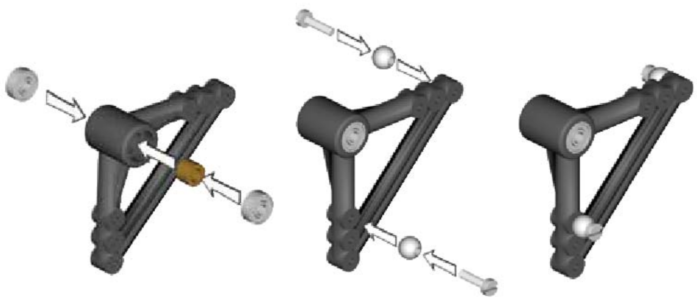




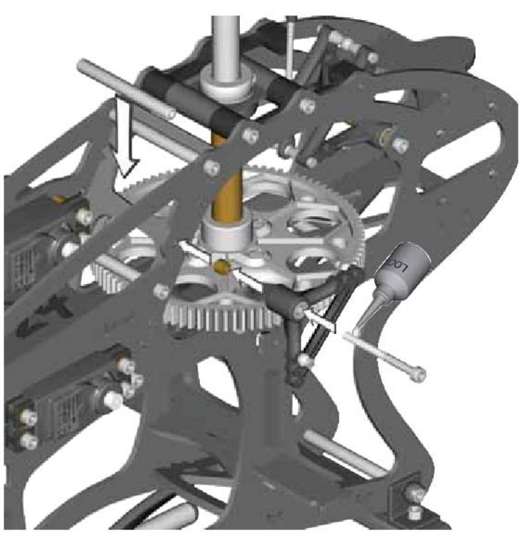
# 1 Main Frame

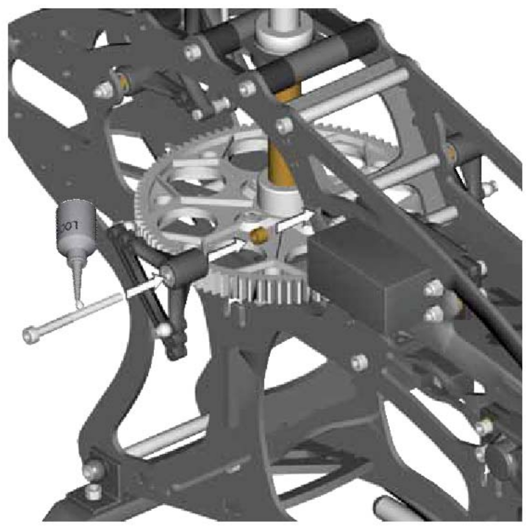
## 1.12 Aileron Lever

**Bag 4 • Bag 12**



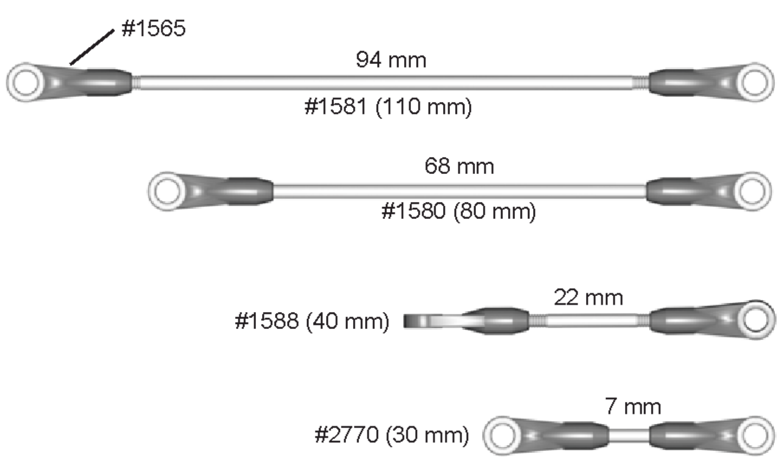
| | | | |
|---|---|---|---|
| 4x | | M2x8 | #1902 |
| 4x | | | #1570 |
| 2x | | 3x5x4 | #924 |
| 2x | | M3x25 | #1958 |
| 4x | | 3x7x3 | #930 |
| 2x | | 3x5x7 | #822 |
| 1x | | 5x45,5mm | #816 |





## 1.13 Linkages

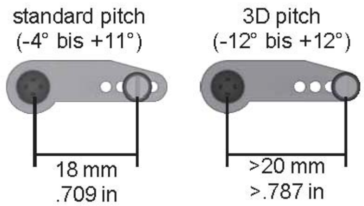
**Bag 1 • Bag 12**



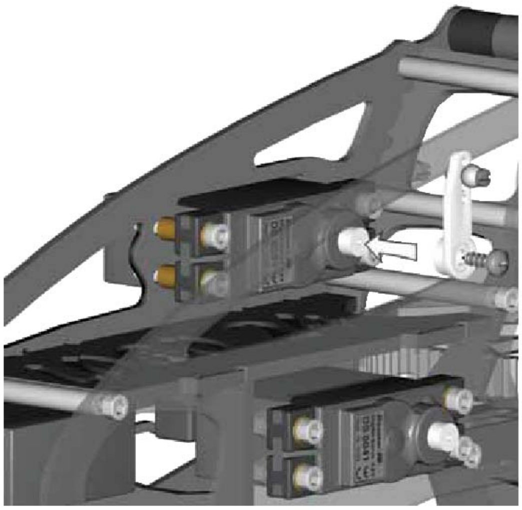
## 1.14 Servo Arms

**Bag 4 • Bag 12**

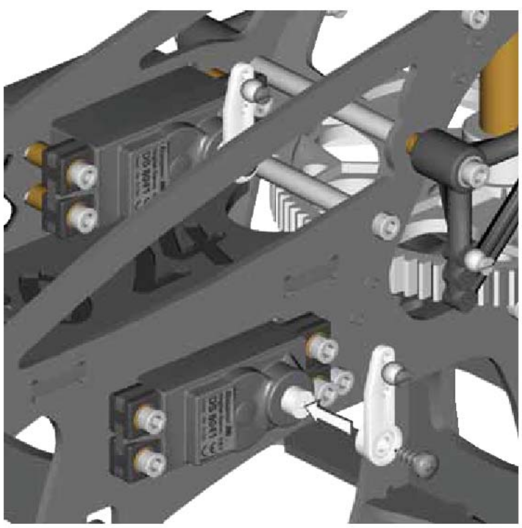
| | | |
|---|---|---|
| 3x | M2x8 | #1902 |
| 3x | | #1570 |
| 3x | M2 | #2070 |



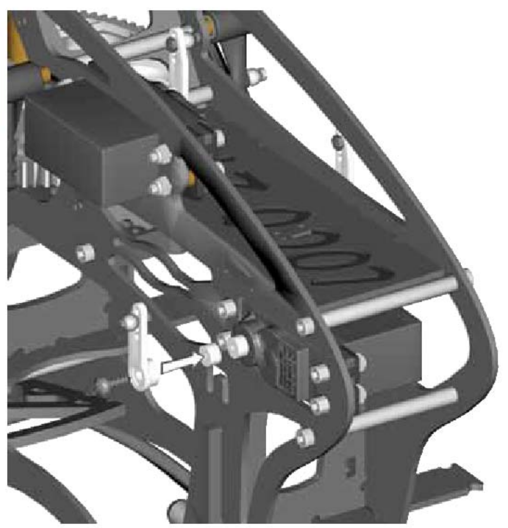




servo arm elevator servo

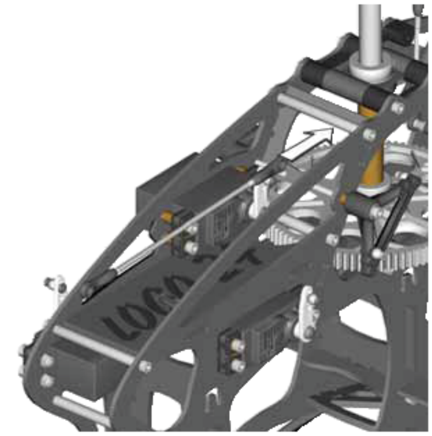


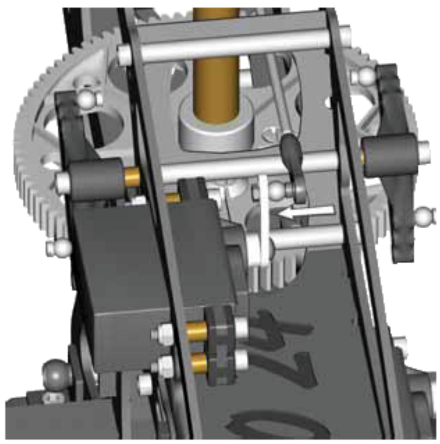
servo arm aileron left

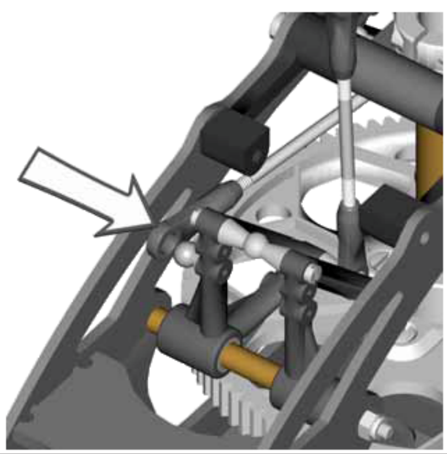


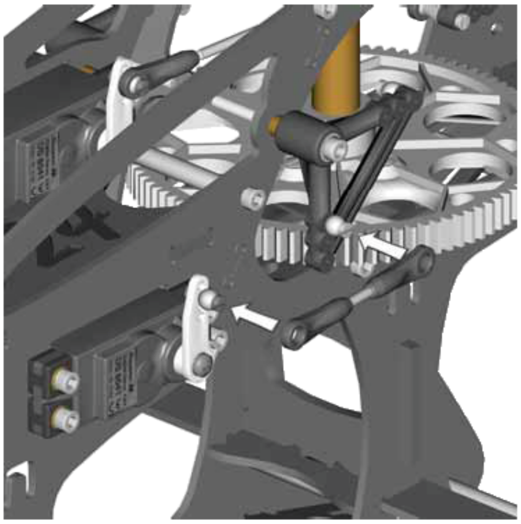
servo arm aileron right

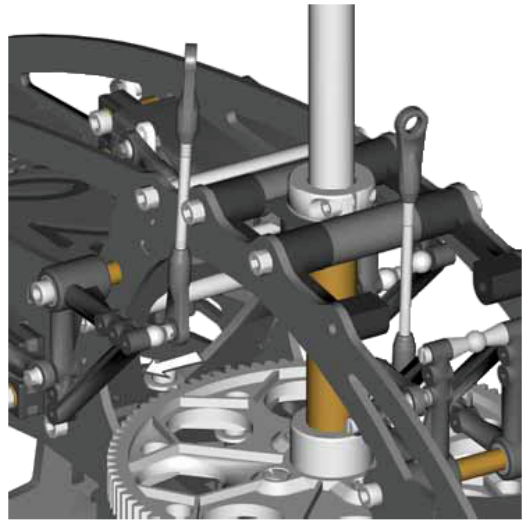
## 1.15 Elevator Linkage

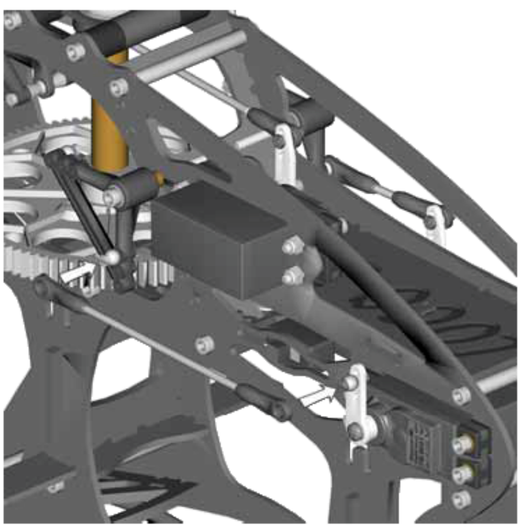


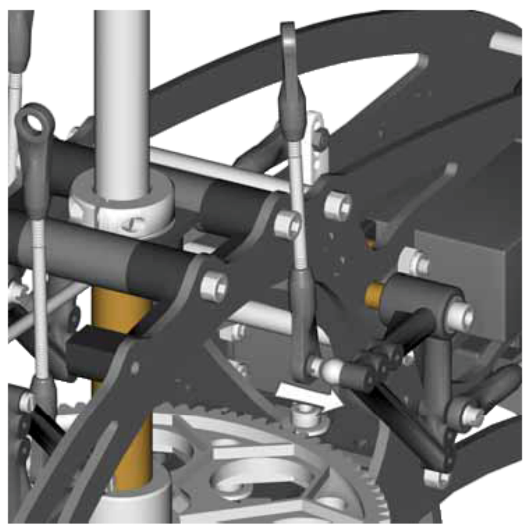






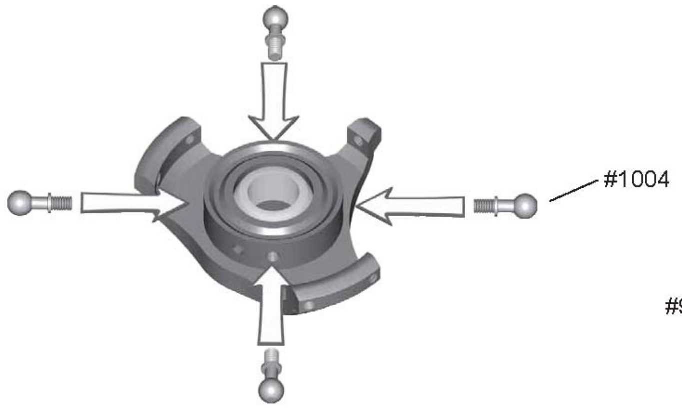


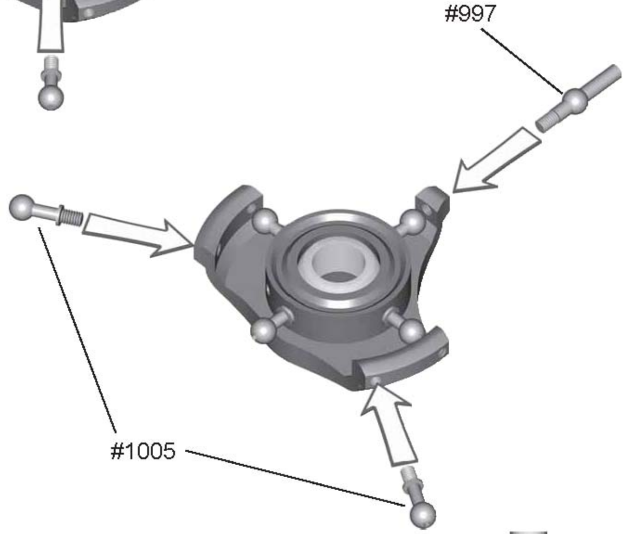


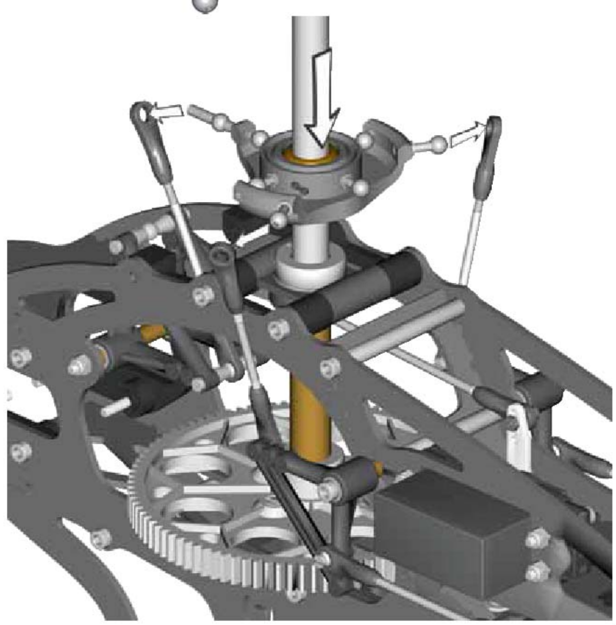


## 1.17 Swashplate

**Bag 3**



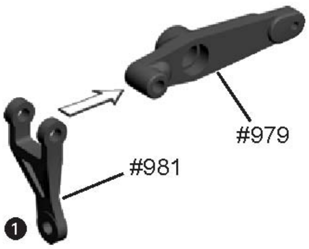



## 1.18 Washout

**Bag 3 • Bag 10 • Bag 12**

| | | |
|---|---|---|
| 2x | 2x8mm | #980 |
| 2x | M2x8 | #1902 |
| 2x | Ø4,8 mm | #1570 |
| 4x | 3x7x3 | #930 |
| 2x | 3x5x2,1 | #2463 |
| 2x | M3x14 | #1955 |
| 2x | 3x5x0,5 | #2002 |

The Y-rods #981 must be able to move easily on the wash-out.

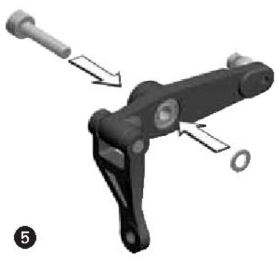



1

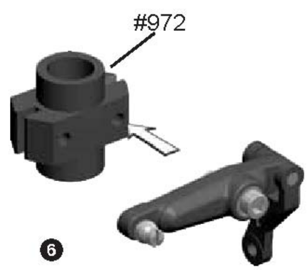
2


3

4

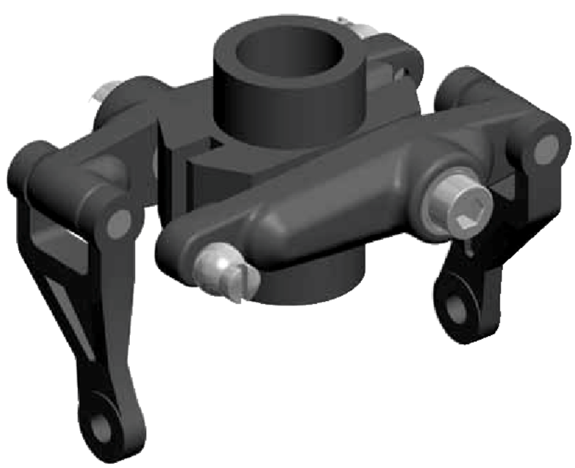


5



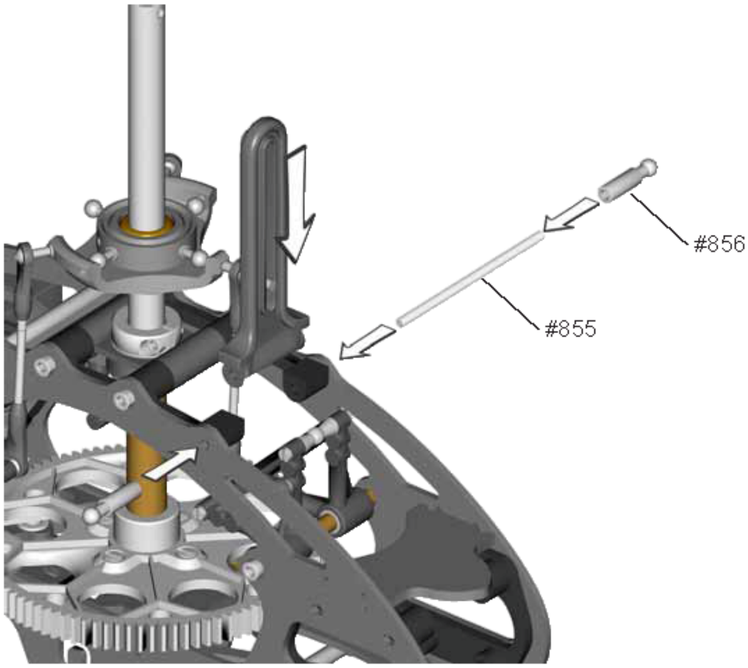

6

7

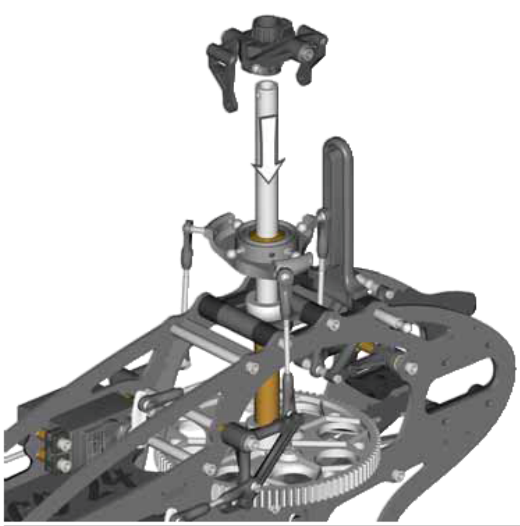


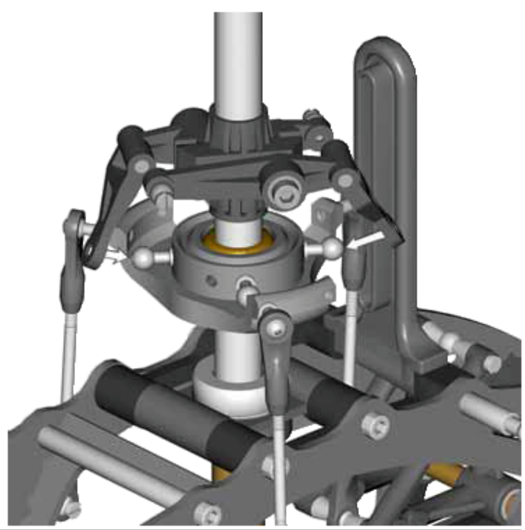
## 1.19 Swashplate Guide

Bag 1

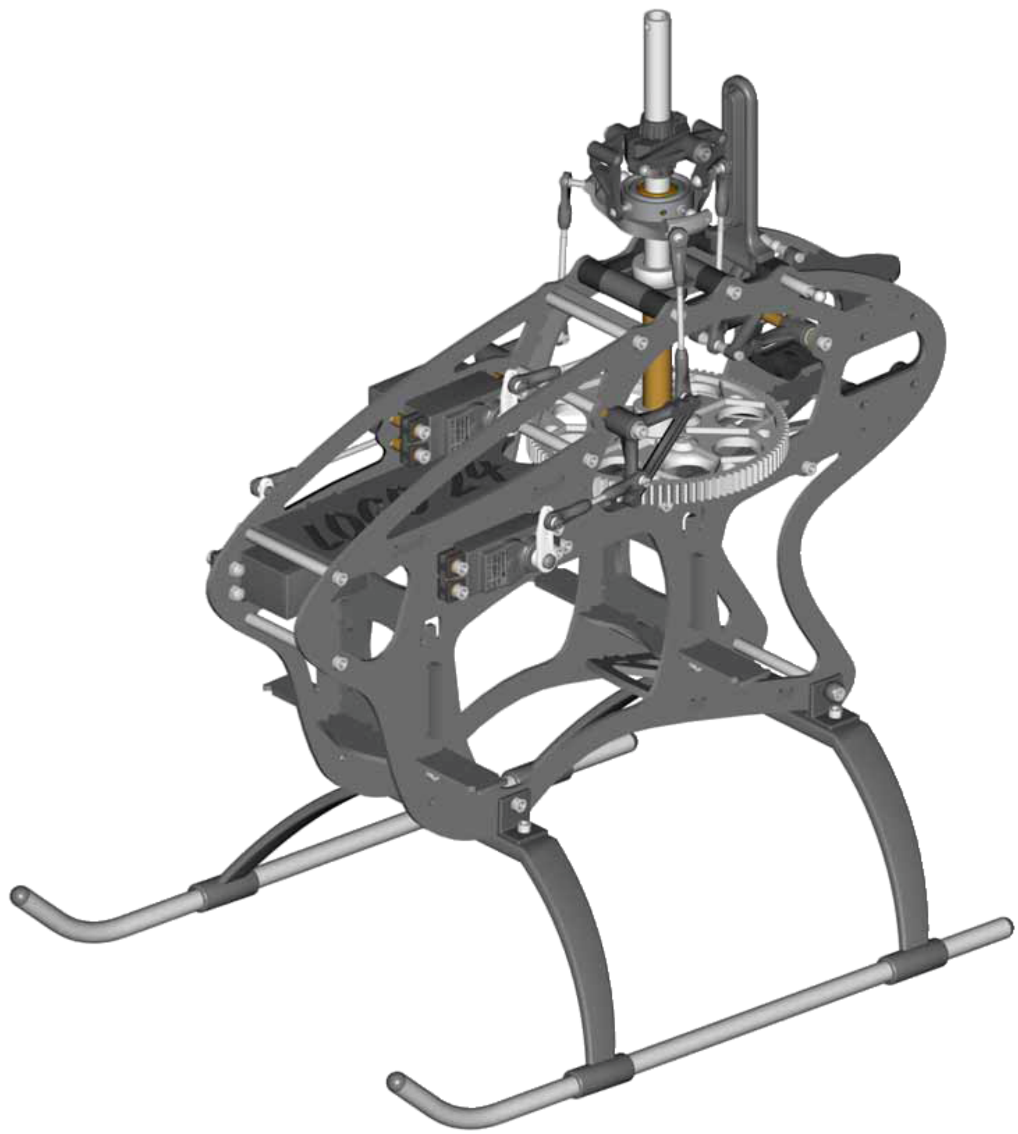



## 1.20 Installation of Washout





## 1.21 Finished Main Frame



# 2 Motor Installation

## 2.1 Motor Installation and Pinion

**Bag 1 • Bag 12**

| | | |
|---|---|---|
| 2x | M3 | #2072 |
| 2x | M3x8 | #1915 |
| 2x | M3x12 | #1964 |
| 2x | 3x7x0,5 | #2012 |


Some electric motors are constructed such that they cannot be moved along the motor plate. If you are using one of these motors, please use the motor adaptor plate #2499. The plate is not needed for Hacker motors.

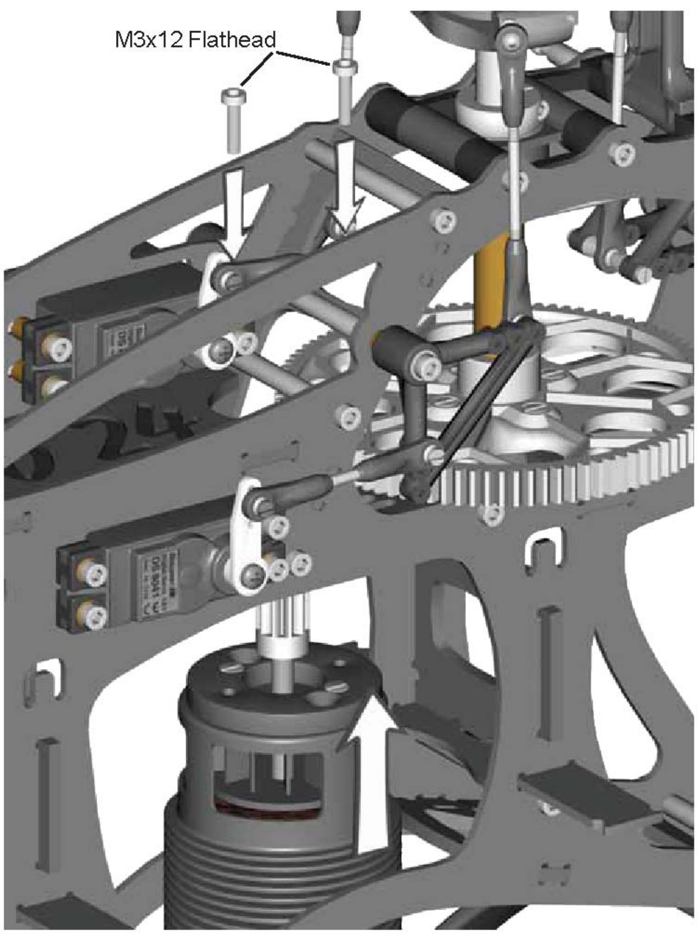
Please check from the Mikado website which pinion works best with the motorset you have (on the Mikado webpage go to LOGO 24 and click "Motorization"). When a wrong pinion is used, the performance of your electric helicopter will deteriorate and the motor or speed controller can be damaged.

Do not tighten the set screw fully until the final position of the pinion on the motor shaft is determined. This is done after installing the main gear.

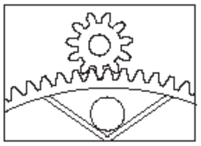
There are two options for attaching the pinion:

1. For securing the pinion, you may flatten the motor shaft where the set screw meets the motor shaft - without making a flat surface on the motor shaft.

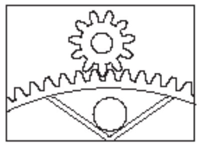
2. Alternatively, you may screw the set screw directly onto the motor shaft. For this it is required that the set screw has an appropriate rim for engaging in the motorshaft (all Mikado pinions have this rim). Note, however, that after attaching the set screw once, this rim becomes blunt so that the screw may not be used again.



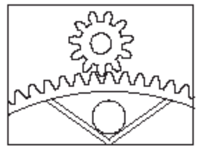
## 2.2 Adjusting Gear Backlash



too little backlash

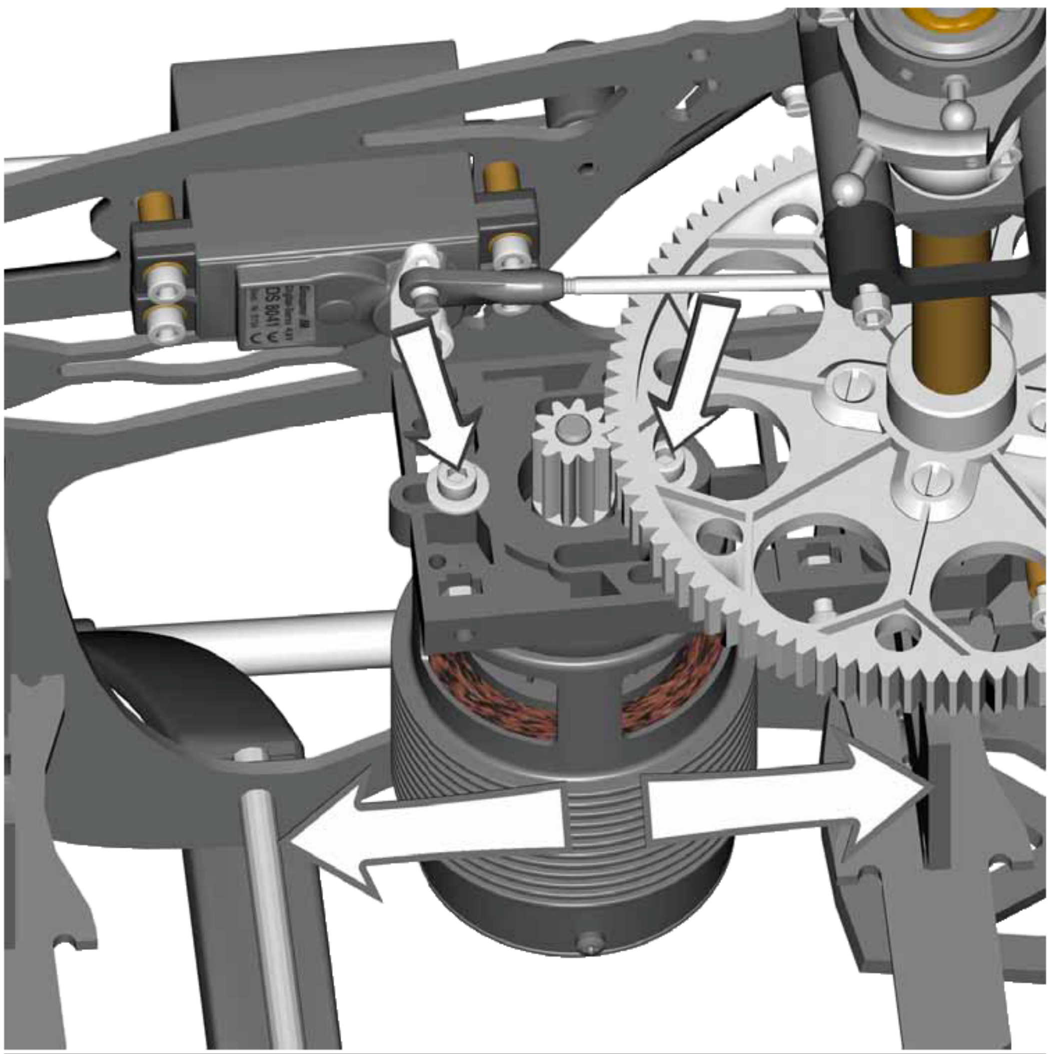


correct backlash



too much backlash

The gear backlash must be adjusted (see drawings). Excess backlash can cause premature wear of the main gear and will lead to shorter flight times.



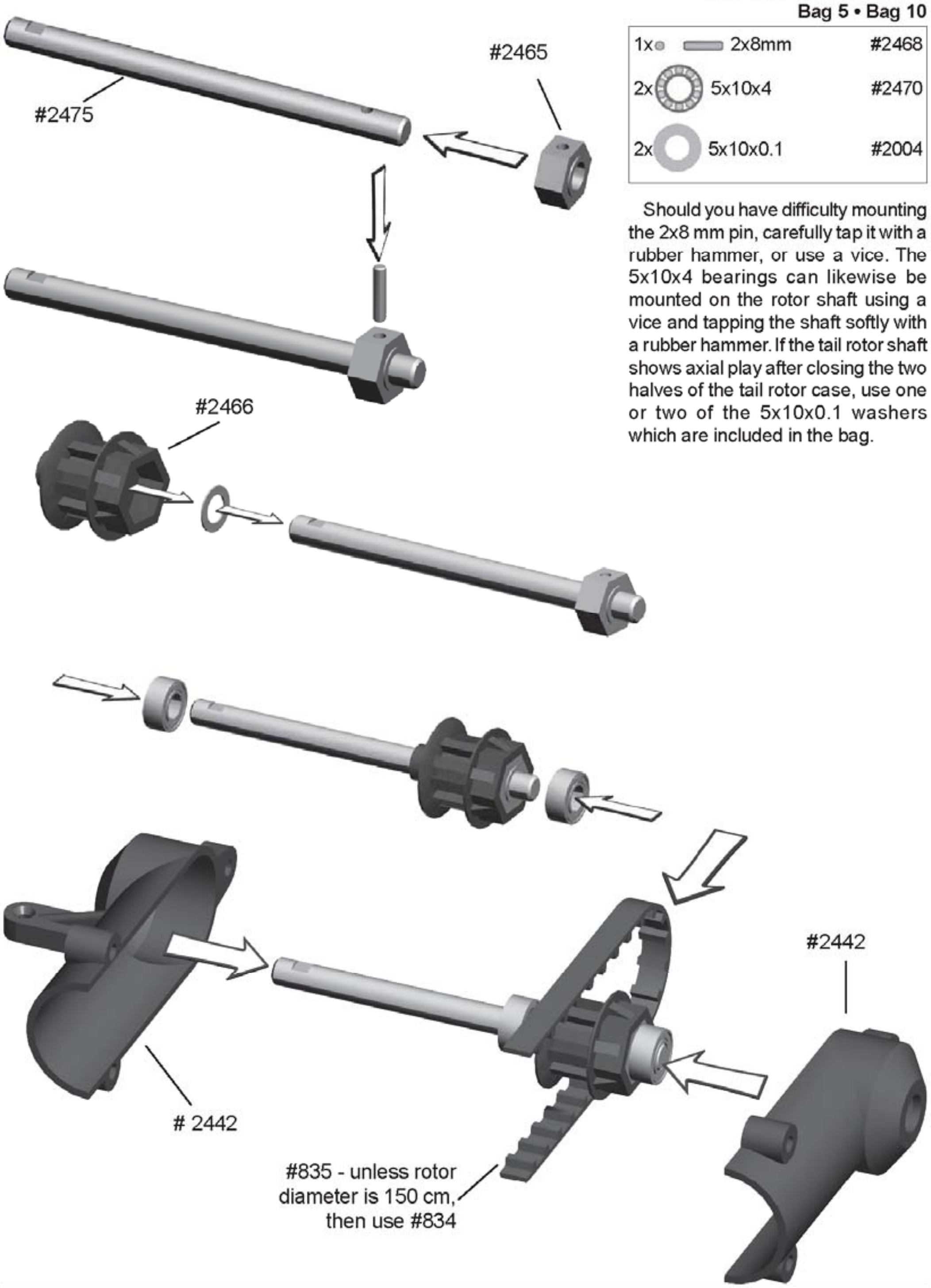
# 3 Tail Rotor

## 3.1 Tail Rotor Shaft

**Bag 5 • Bag 10**

| | | | |
|---|---|---|---|
| 1x | | 2x8mm | #2468 |
| 2x | | 5x10x4 | #2470 |
| 2x | | 5x10x0.1 | #2004 |

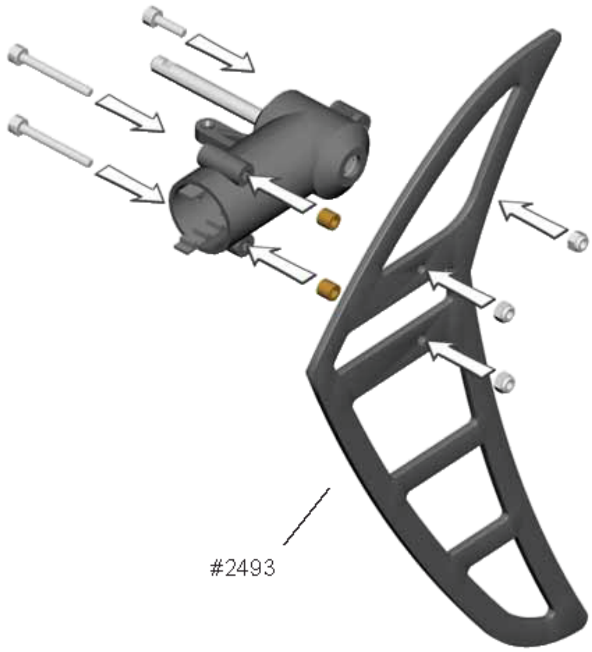
Should you have difficulty mounting the 2x8 mm pin, carefully tap it with a rubber hammer, or use a vice. The 5x10x4 bearings can likewise be mounted on the rotor shaft using a vice and tapping the shaft softly with a rubber hammer. If the tail rotor shaft shows axial play after closing the two halves of the tail rotor case, use one or two of the 5x10x0.1 washers which are included in the bag.



## 14.2 Vertical Fin

**Bag 5 • Bag 12**

| | | |
|---|---|---|
| 2x | M3x25 | #1958 |
| 1x | M3x10 | #1953 |
| 3x | M3 | #2074 |
| 2x | 3x5x4 | #924 |



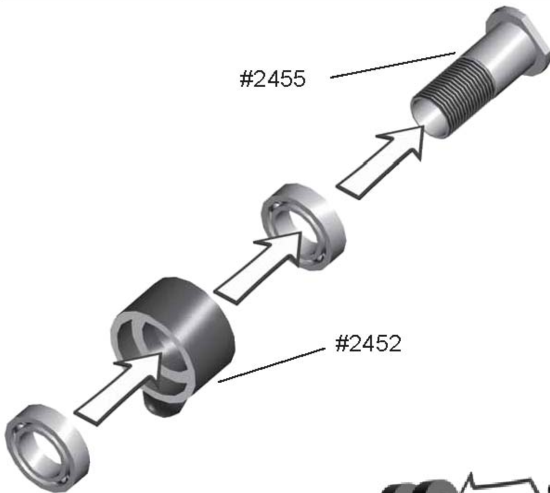

## 3.3 Tail Pitch Slider

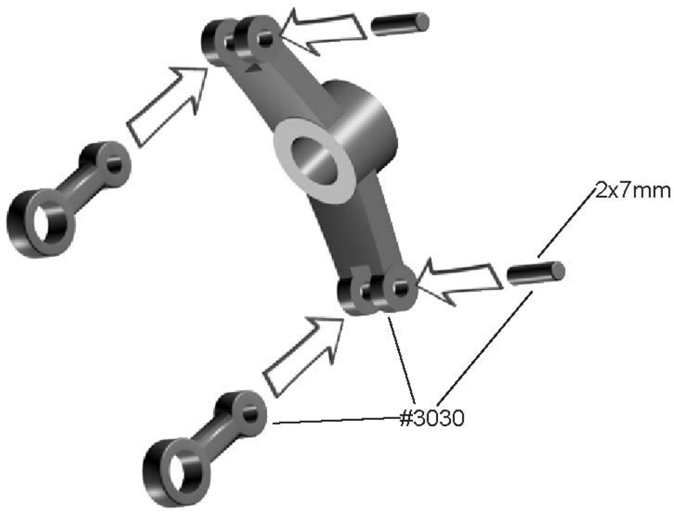
**Bag 5 • Bag 10**

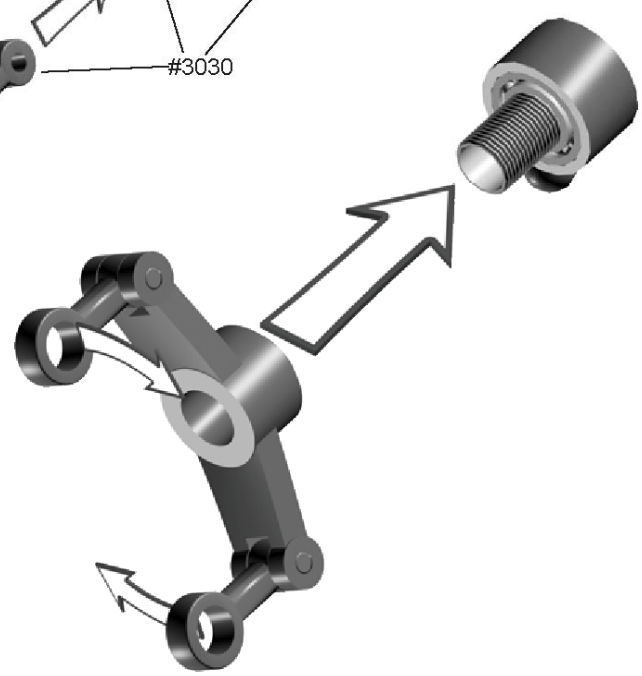
| | | |
|---|---|---|
| 2x | 6x10x2,5 | #1440 |

It is important that the tail pitch plate #2450 is aligned properly on the control sleeve #2455. In the case of misalignment, the control sleeve may become deformed.

The mounted tail pitch plate should be able to move on the tail rotor shaft with little resistance.



# 3 Tail Rotor

## 3.3 Tail Pitch Slider

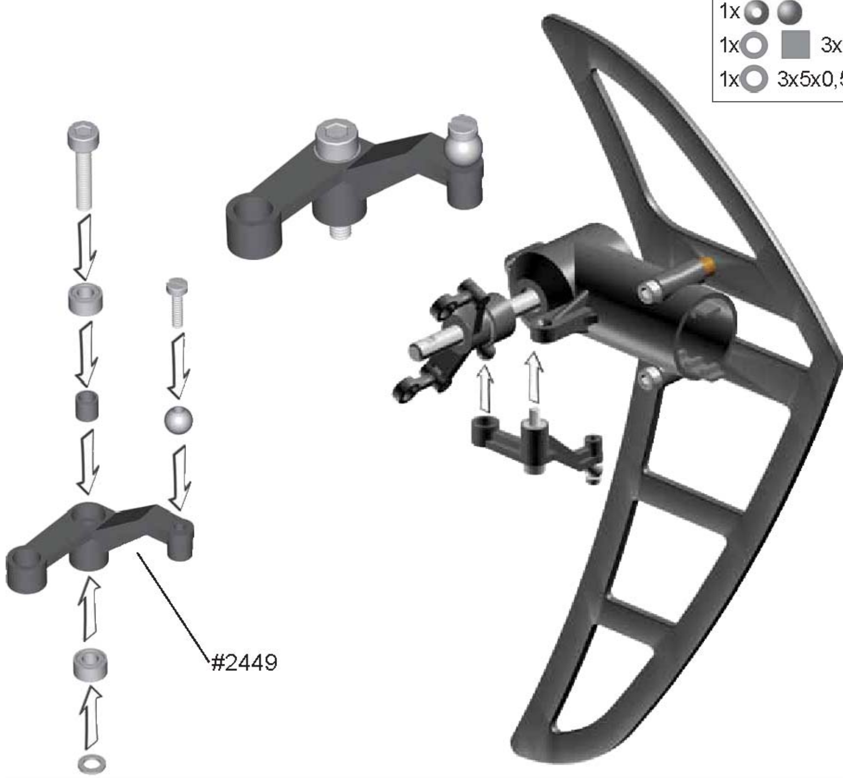
**Bag 5 • Bag 12**

The mounted tail rotor lever should be able to move with little resistance.

## 3.3 Tail Rotor Lever

**Bag 5 • Bag 10 • Bag 12**

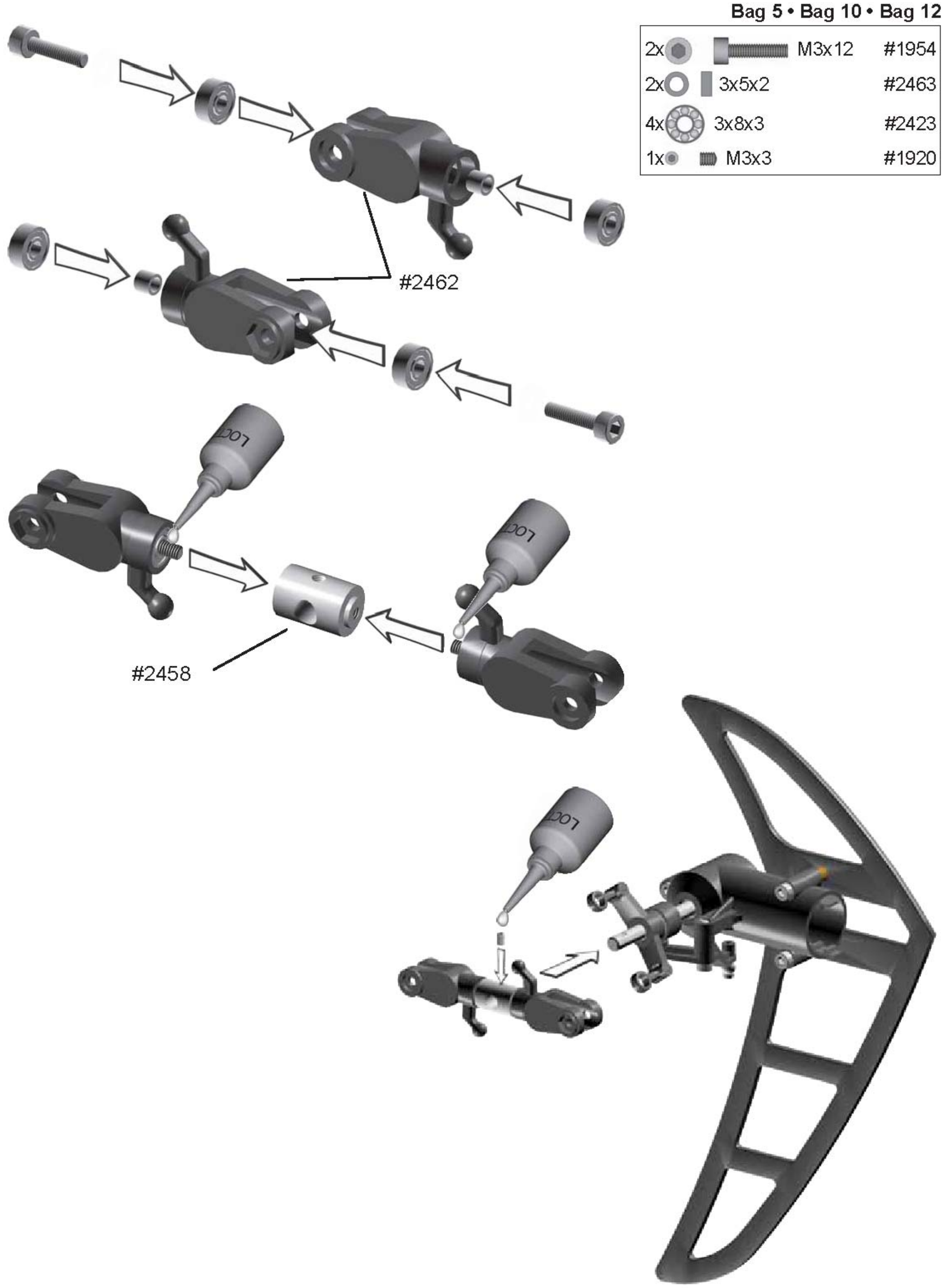
| | | |
|---|---|---|
| 2x | 3x6x2,5 | #2330 |
| 1x | M3x14 | #1955 |
| 1x | M2x8 | #1902 |
| 1x | | #1570 |
| 1x | 3x5x5 | #2448 |
| 1x | 3x5x0,5 | #2002 |



## 3.5 Tail Rotor Hub

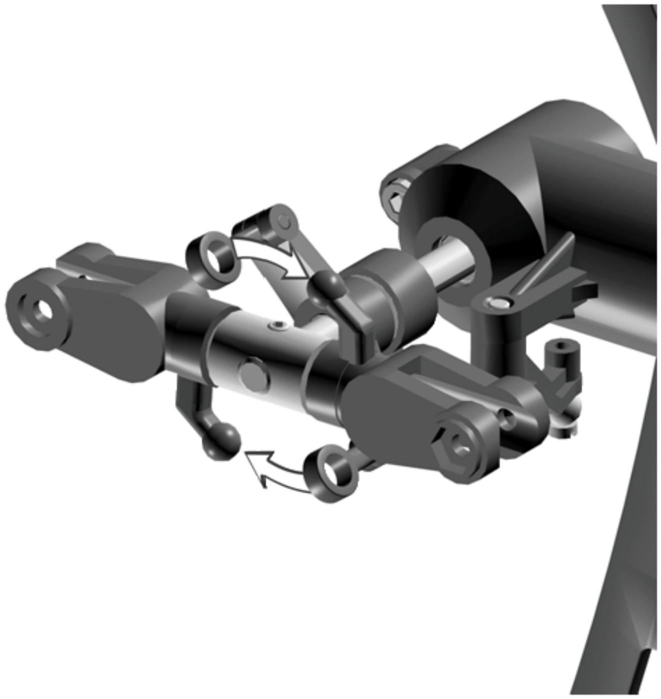
**Bag 5 • Bag 10 • Bag 12**

| | | |
|---|---|---|
| 2x | M3x12 | #1954 |
| 2x | 3x5x2 | #2463 |
| 4x | 3x8x3 | #2423 |
| 1x | M3x3 | #1920 |



## 3.5 Tail Rotor Hub

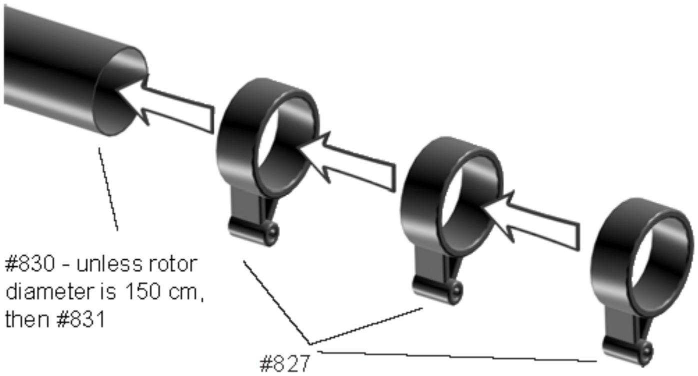
**Bag 5 • Bag 10 • Bag 12**

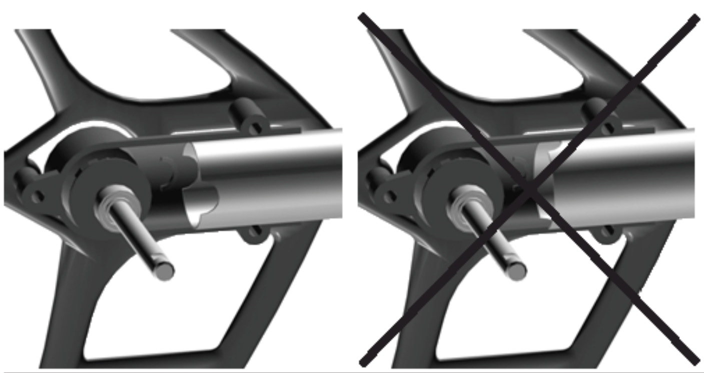


# 4 Tail

## 4.1 Tail Boom Assembly

**Bag 6 • Bag 11**

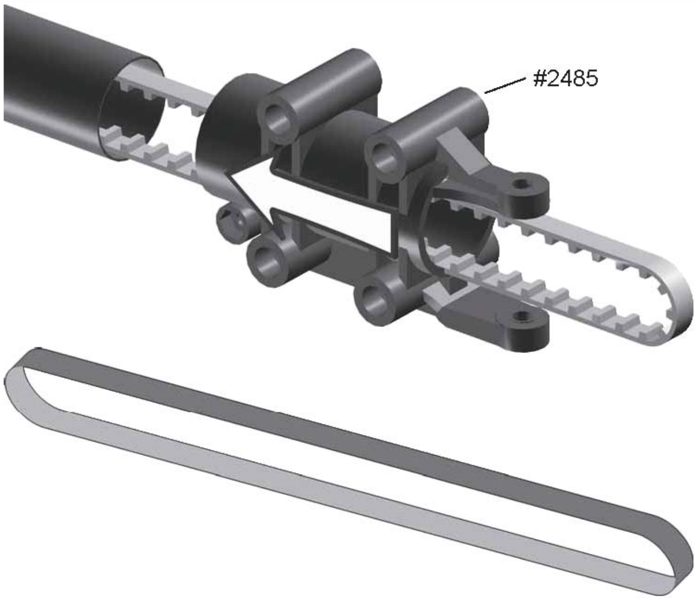


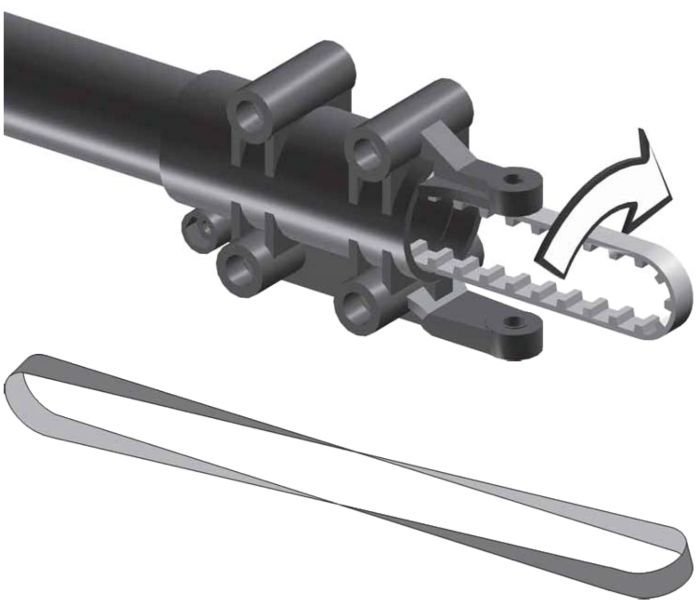



The tail boom has two round cut-outs on one end. These should be fitted into the matching shapes in the tail rotor case.

## 4.2 Tail Boom Holder

**Bag 6**



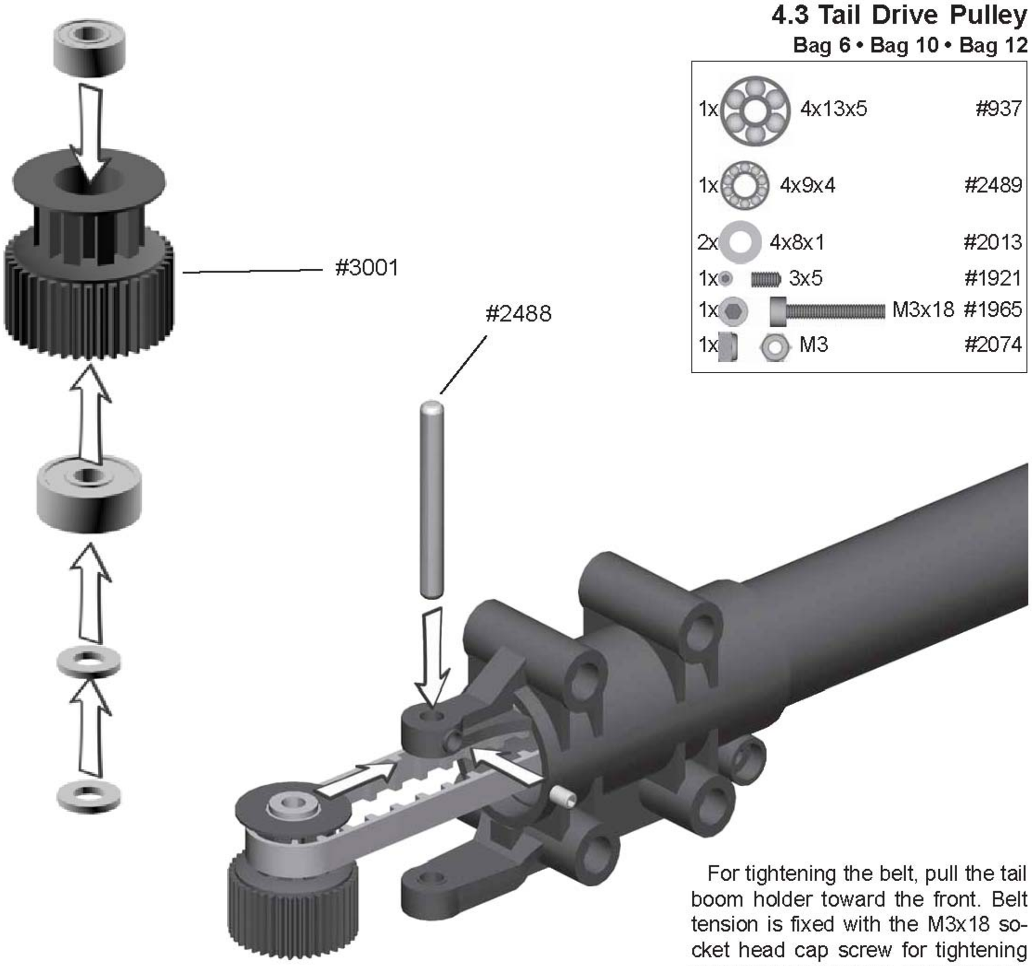



Turn the tail drive belt 90 degrees (clockwise).

## 4.3 Tail Drive Pulley

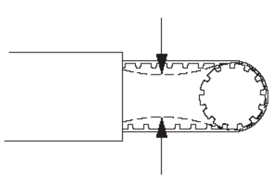
**Bag 6 • Bag 10 • Bag 12**

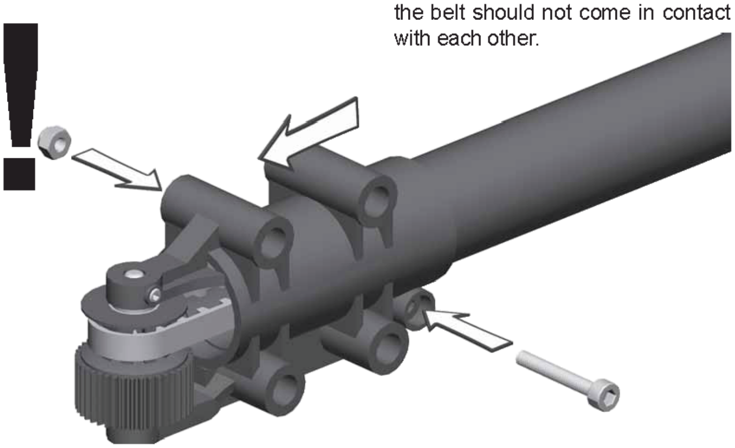
| | | |
|---|---|---|
| 1x | 4x13x5 | #937 |
| 1x | 4x9x4 | #2489 |
| 2x | 4x8x1 | #2013 |
| 1x | 3x5 | #1921 |
| 1x | M3x18 | #1965 |
| 1x | M3 | #2074 |




For tightening the belt, pull the tail boom holder toward the front. Belt tension is fixed with the M3x18 socket head cap screw for tightening the tail boom holder to the tail boom. The belt should be tight. When pressing with your fingers, both sides of the belt should not come in contact with each other.

**Important:** Check belt tension prior to every flight. Incorrect belt tension can cause disturbances for your model R/C system. Incorrect belt tension can lead to a situation where you lose control of the tail rotor of your helicopter.



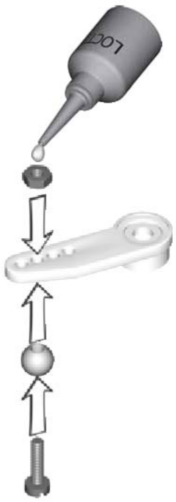


# 4 Tail

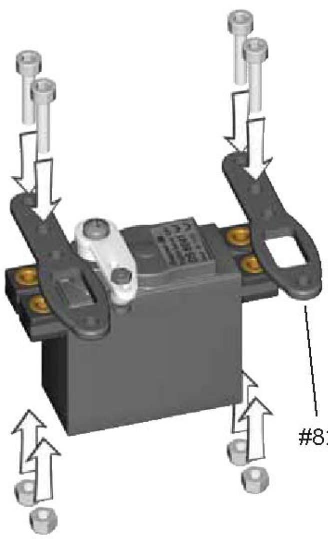
## 4.4 Tail Servo Holder

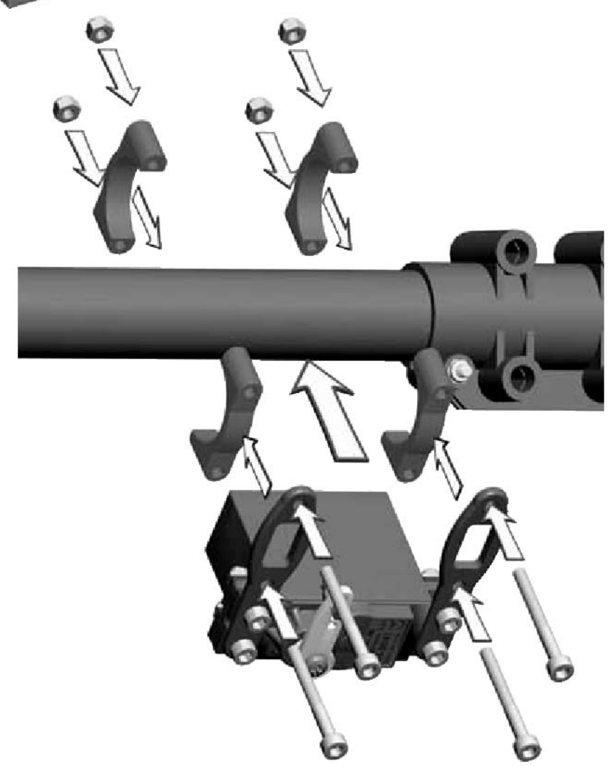
**Bag 6 • Bag 10 • Bag 12**

| | | |
|---|---|---|
| 4x | M3x12 | #1954 |
| 4x | M3x25 | #1958 |
| 1x | M2x8 | #1902 |
| 1x | | #1570 |
| 1x | M2 | #2070 |
| 8x | Stopp M3 | #2074 |



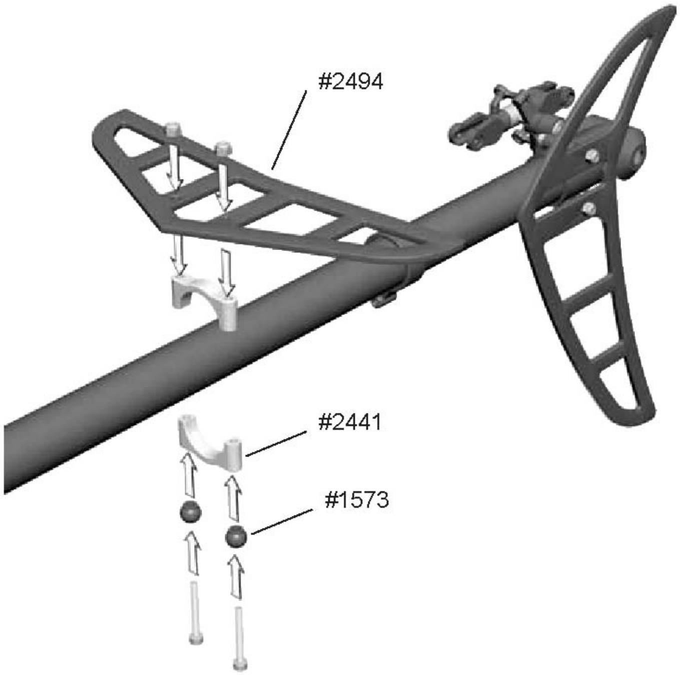

If you are using Futaba-Servos leave out the metal washers. Through the servos into the frame using only the rubber pieces.

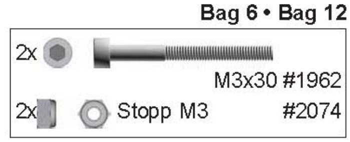


### 4.5 Horizontal Fin

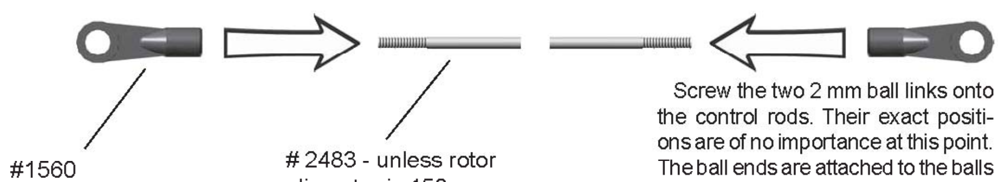
**Bag 6 • Bag 12**



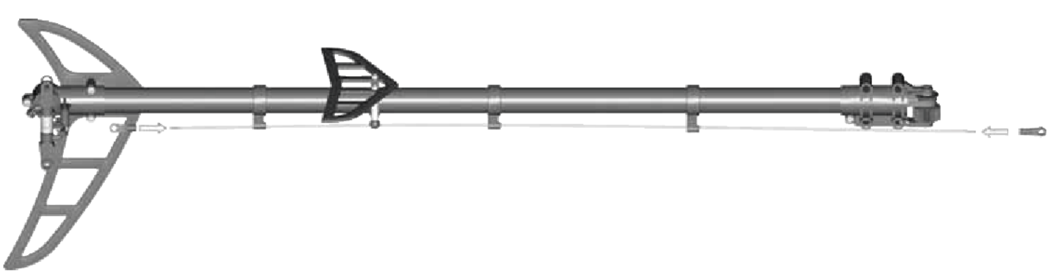



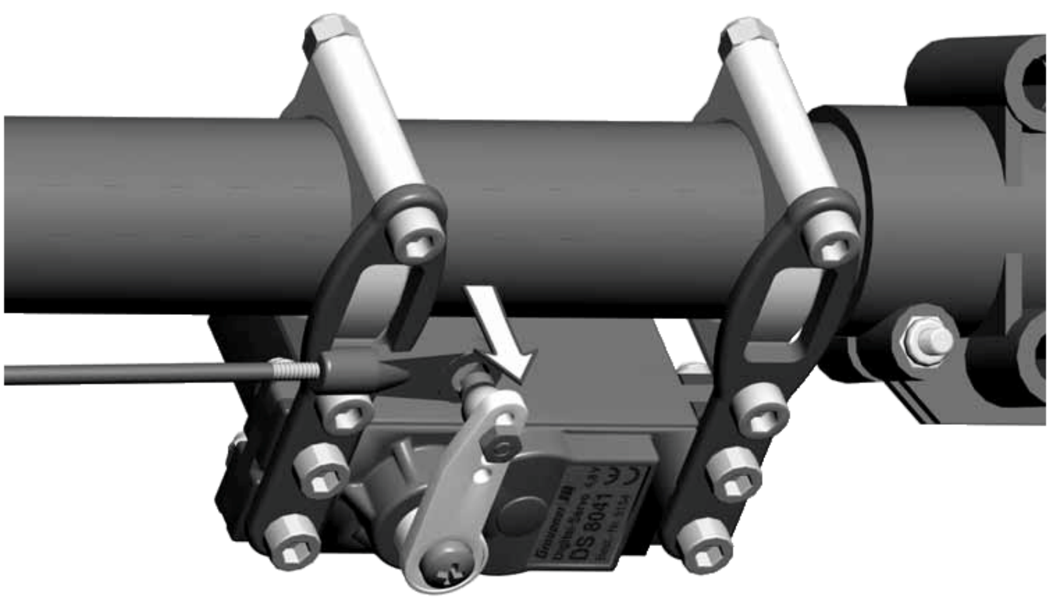

### 4.6 Tail Control Rods

**Bag 11 • Bag 12**



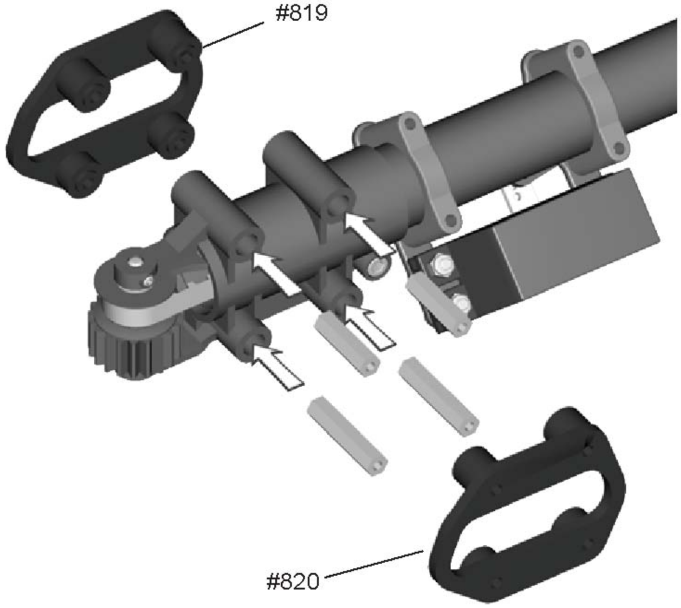

Screw the two 2 mm ball links onto the control rods. Their exact positions are of no importance at this point. The ball ends are attached to the balls more easily when the text on them is pointed away from the helicopter.

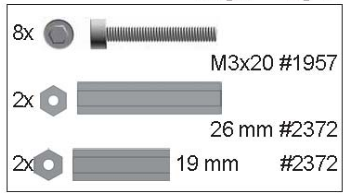


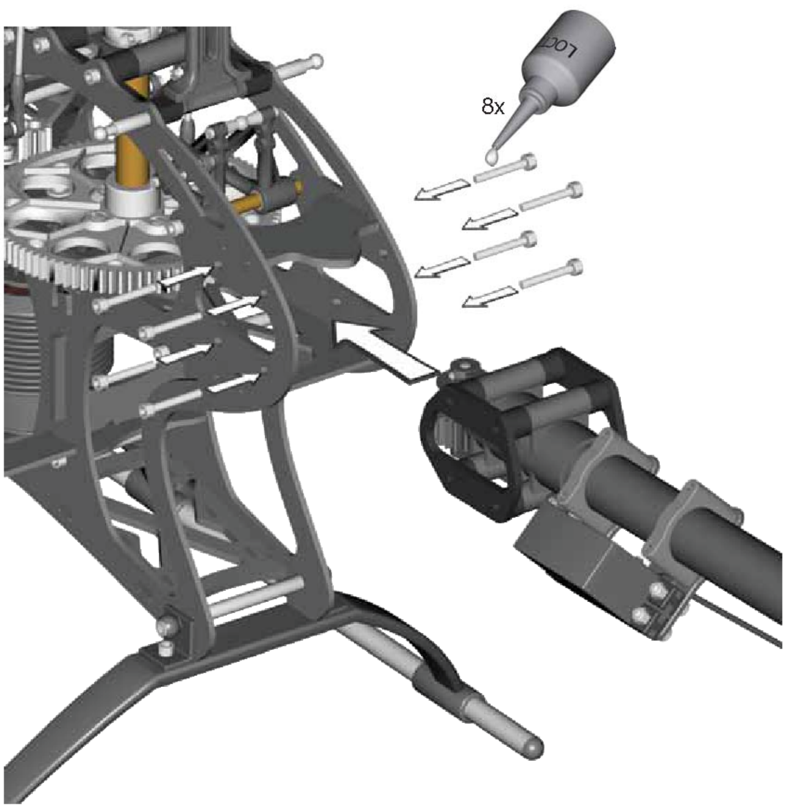


## 4.7 Tail Assembly

**Bag 6 • Bag 12**

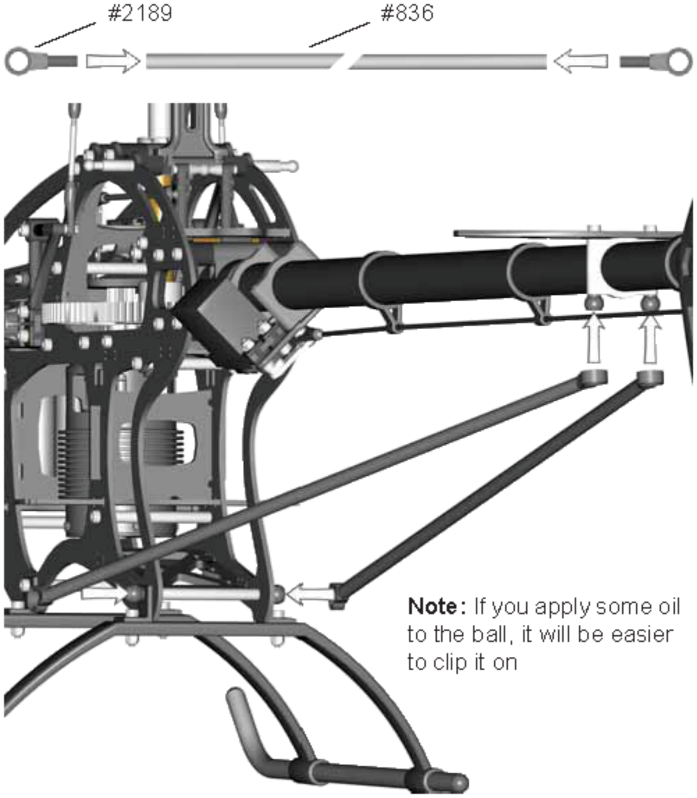


## 4.8 Tail Boom Brace

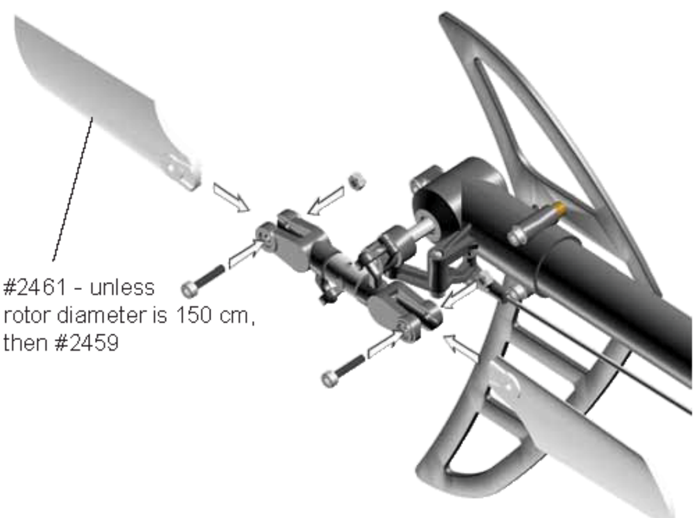
**Bag 6 • Bag 11**




## 4.9 Tail Rotor Blades

**Bag 5 • Bag 12**

| | | | |
|---|---|---|---|
| 2x | | M3x14 | #1955 |
| 2x | | Stopp M3 | #2074 |

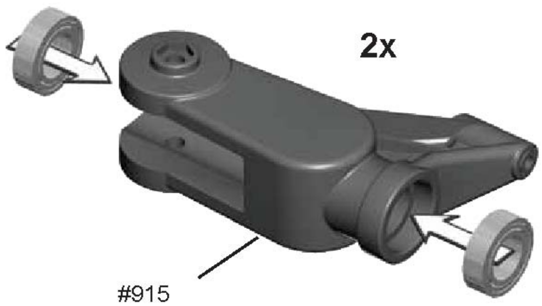


## 4.10 Main Frame with Tail Boom

## 5.1 Blade Grips

**Bag 7 • Bag 10**

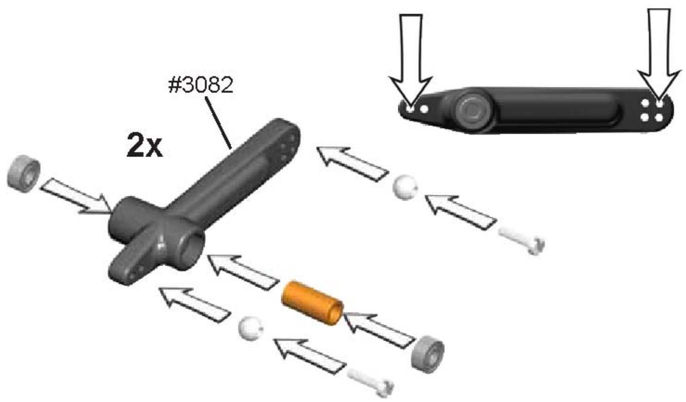
| | | |
|---|---|---|
| 4x | 8x16x5 | #954 |

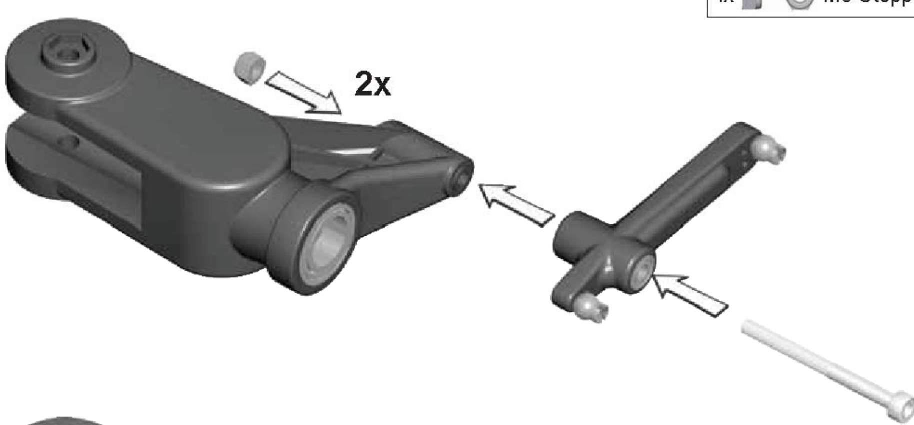


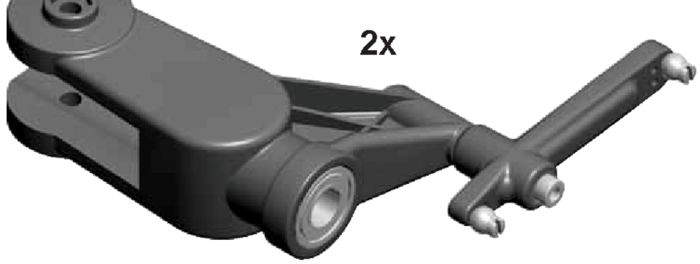

## 5.2 Mixing Arms

**Bag 7 • Bag 10 • Bag 12**

| | | |
|---|---|---|
| 4x | 3x7x3 | #930 |
| 2x | 3x5x12 | #3090 |
| 4x | Ø4,8 mm | #1570 |
| 4x | M2x8 | #1902 |
| 2x | M3x35 | #1961 |
| 4x | M3 Stopp | #2074 |



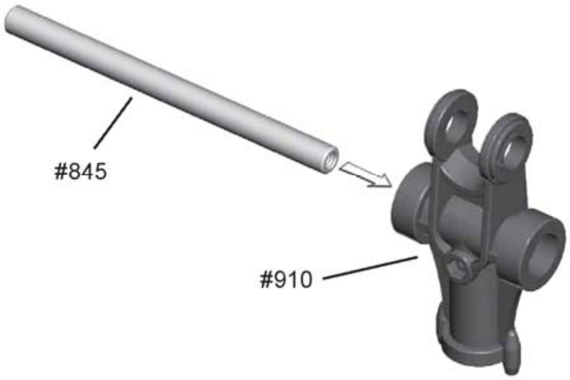



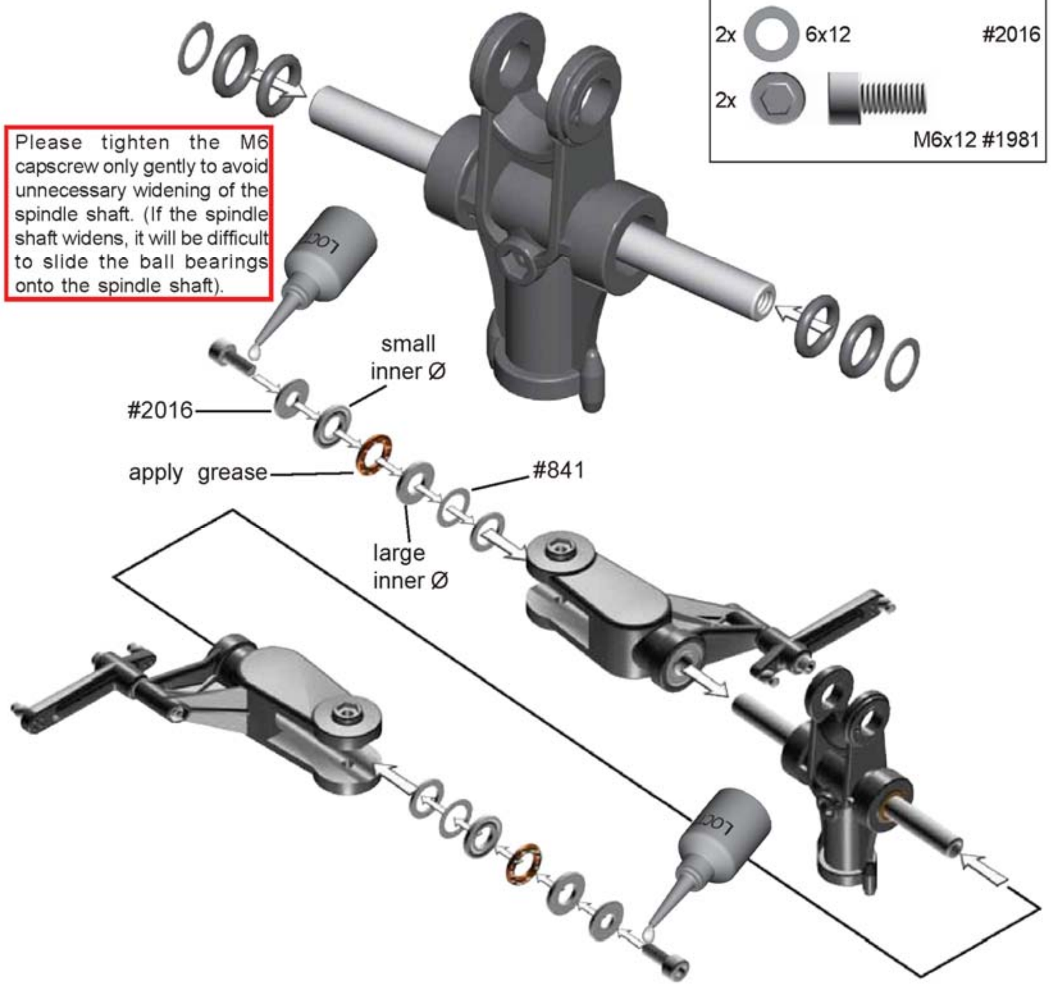



## 5.3 Yoke, Spindle Shaft

**Bag 7 • Bag 10**

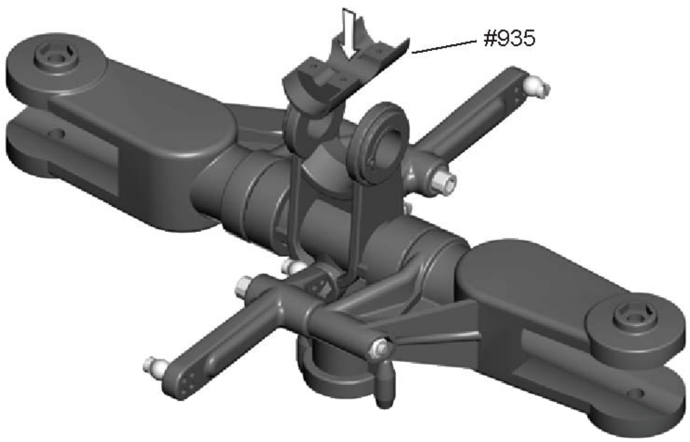
| | | |
|---|---|---|
| 4x | 8x3 mm | #950 |
| 2x | 8x11 mm | #952 |
| 2x | 11,5x16,8x0,8 mm | #841 |
| 2x | 8x16 | #840 |
| 2x | 6x12 | #2016 |
| 2x | M6x12 | #1981 |



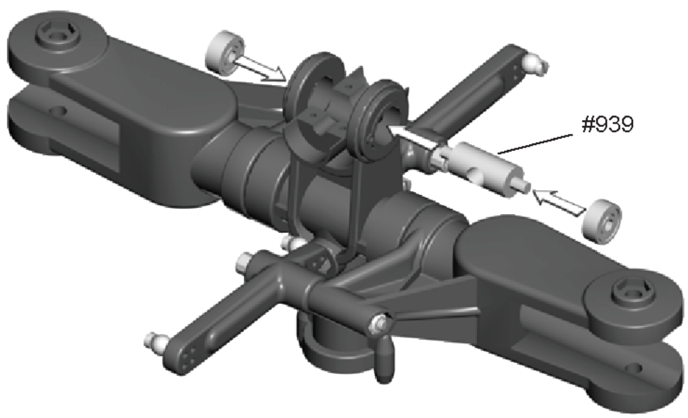



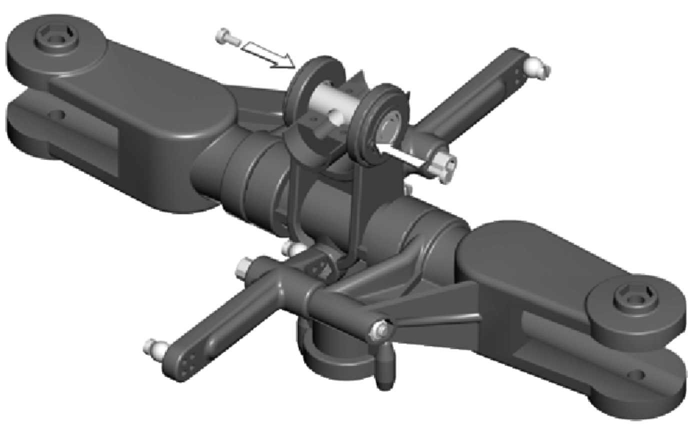
## 5.4 Seesaw

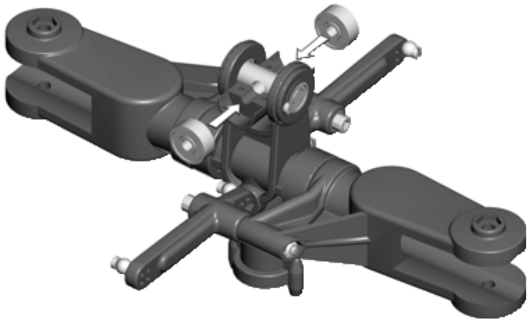
**Bag 7 • Bag 10 • Bag 12**

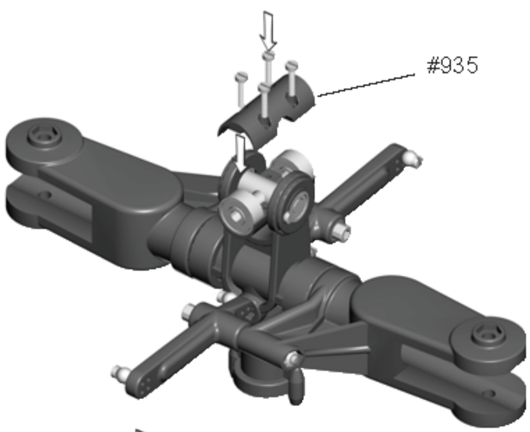



| | | | |
|---|---|---|---|
| 2x | 4x13x5 | | #937 |
| 2x | 4x10x4 | | #726 |
| 4x | | M2x8 | #1902 |
| 2x | | M2x3 | #1900 |



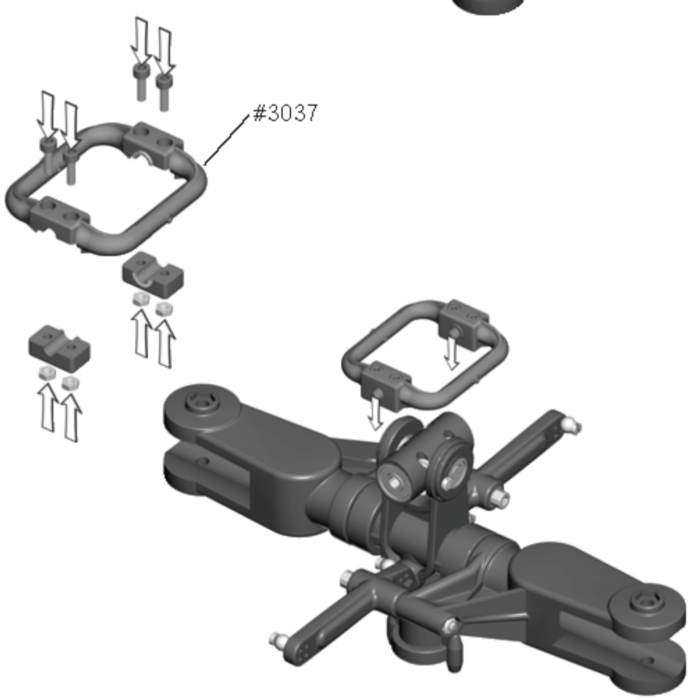





## 5.5 Flybar Control Bridge

**Bag 7 • Bag 10**

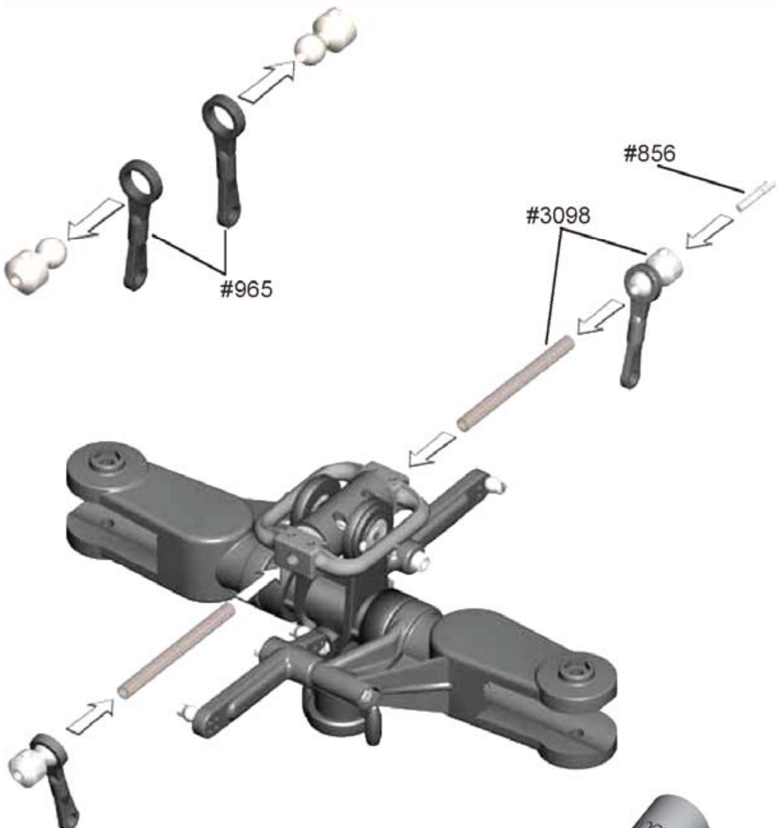
| | | | |
|---|---|---|---|
| 4x | | M2x10 | #1939 |
| 4x | | M2 | #2070 |



# 5 Main Rotor Head

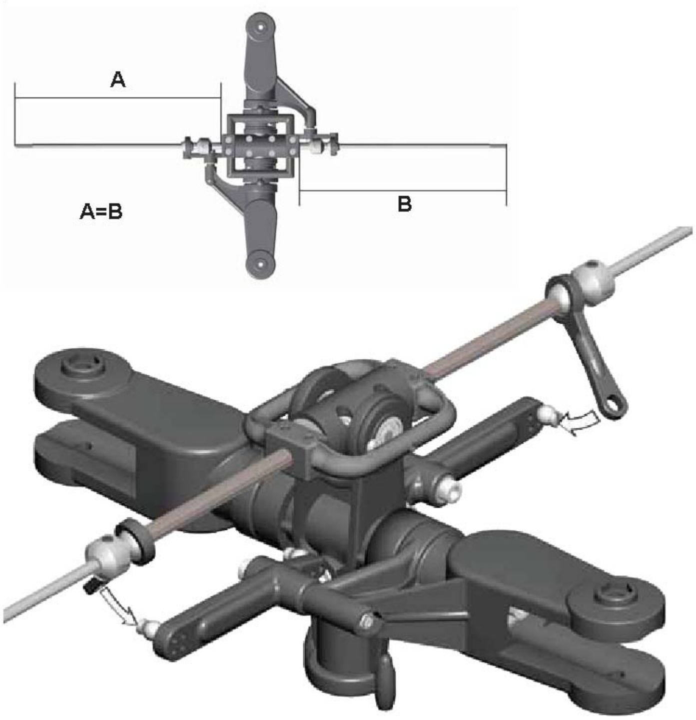
## 5.6 Flybar

**Bag 7 • Bag 11**



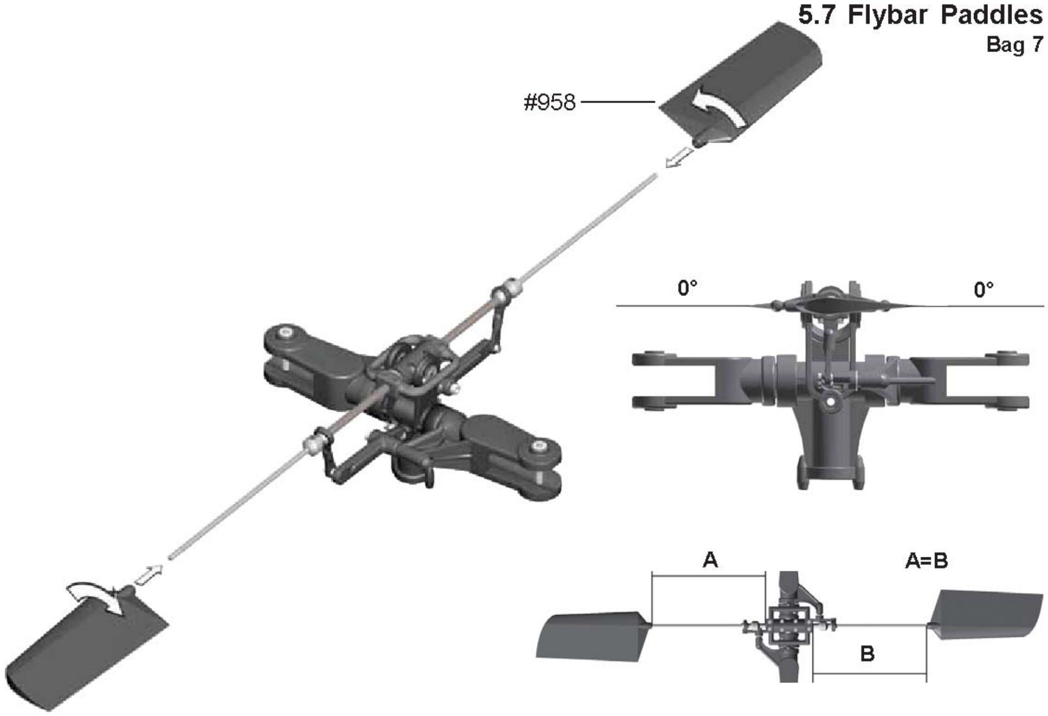


| | | | |
|---|---|---|---|
| 2x | | M3x3 | #1920 |




## 5.7 Flybar Paddles

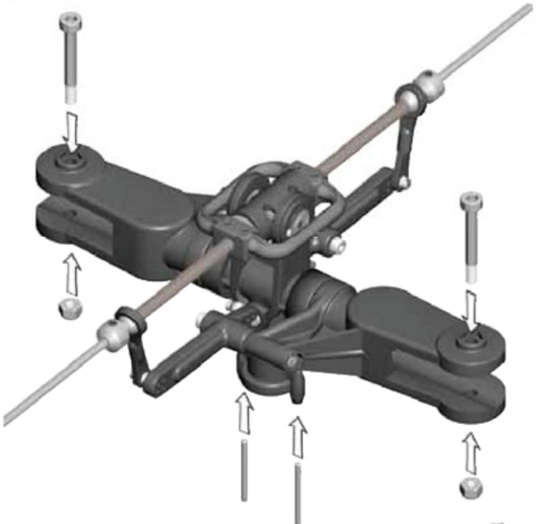
Bag 7



### 17.8 Final Assembly

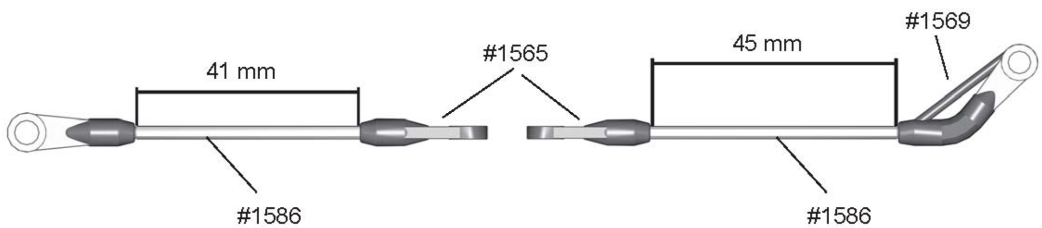
**Bag 7 • Bag 12**

| | | |
|---|---|---|
| 2x | M4x35 | #1974 |
| 2x | M4 | #2076 |
| 2x | 2x30 mm | #912 |
| 1x | M3x18 | #1965 |
| 1x | M3 | #2072 |

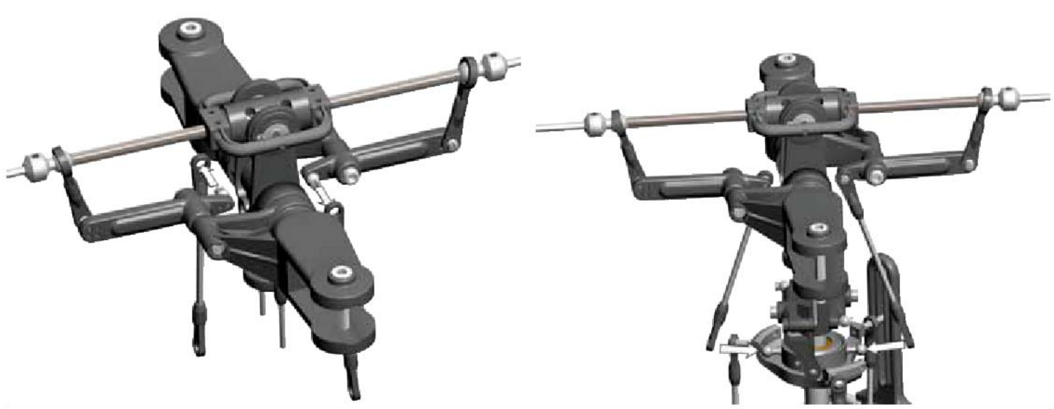


## 5.9 Rotor Head Linkage

**Bag 7 • Bag 12**

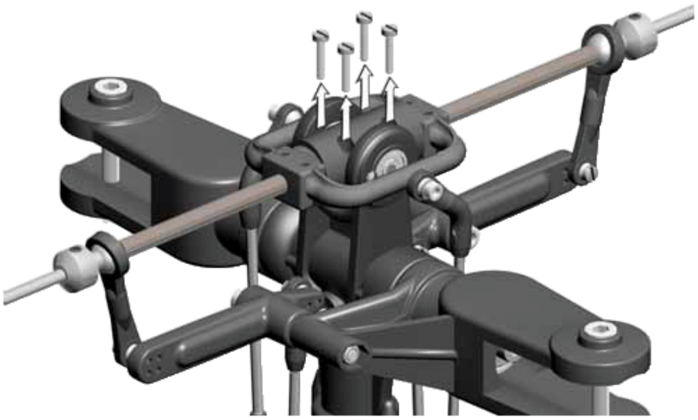



Next, mount the length-adjusted fly-bar control linkages. The ball links are attached to the balls more easily when the text on them points away from the helicopter.



# 5 Main Rotor Head

| | | |
|---|---|---|
| 2x | M2x12 | #1942 |
| 1x | 4,8 | #1571 |
| 1x | 2x4,5x0,5 | #2018 |

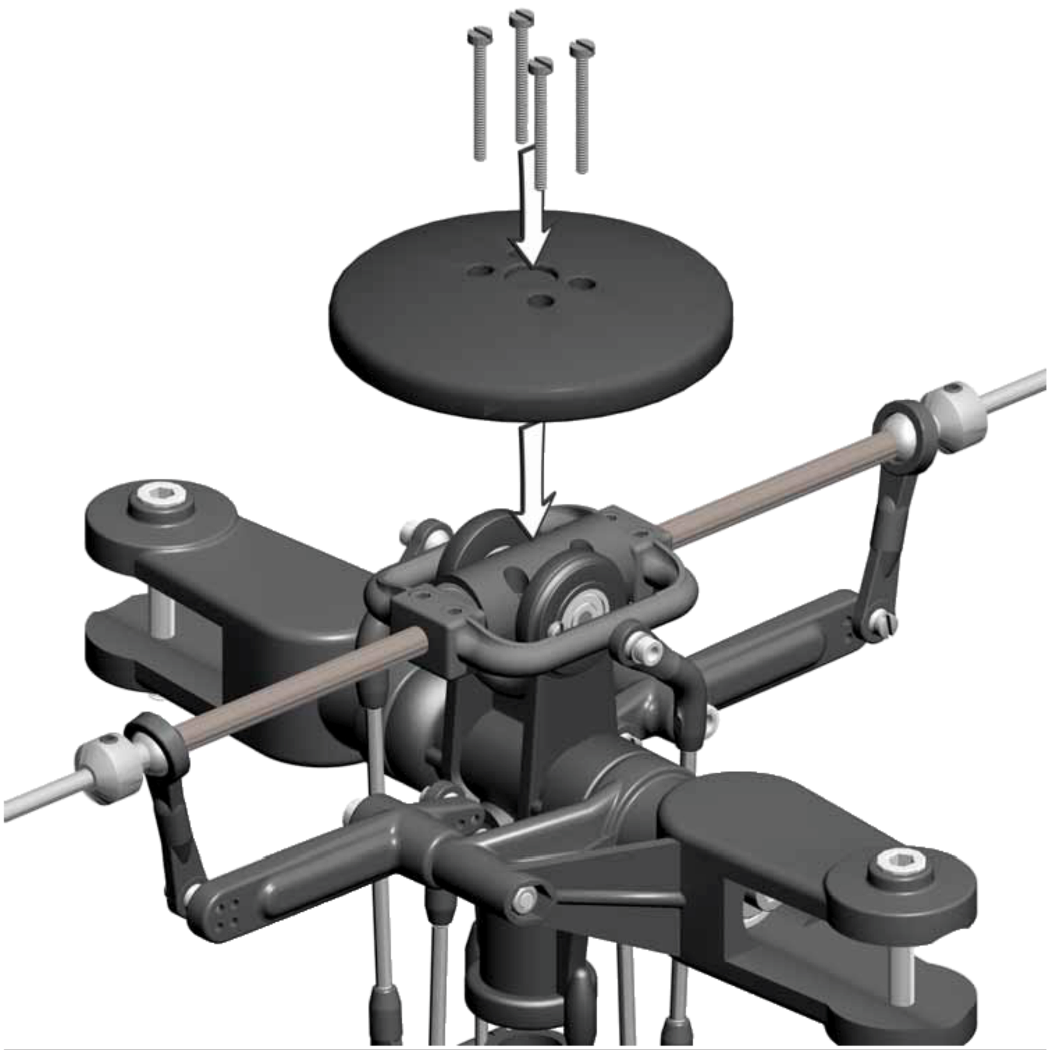


## 17.10 Rotor Disk

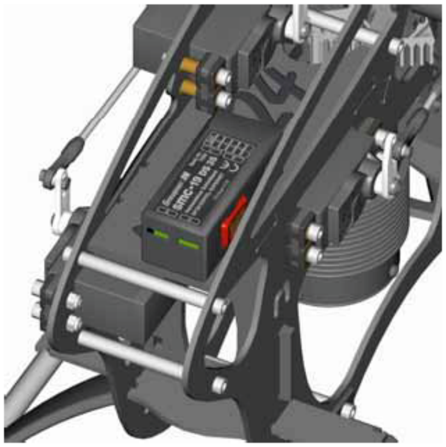
**Bag 7 • Bag 12**

| | | | |
|---|---|---|---|
| 4x | | M2x18 | #1905 |

The rotor disk is not absolutely necessary. However, when it is installed one can more easily stop the rotor head from spinning. In addition, it is a nice visual detail.

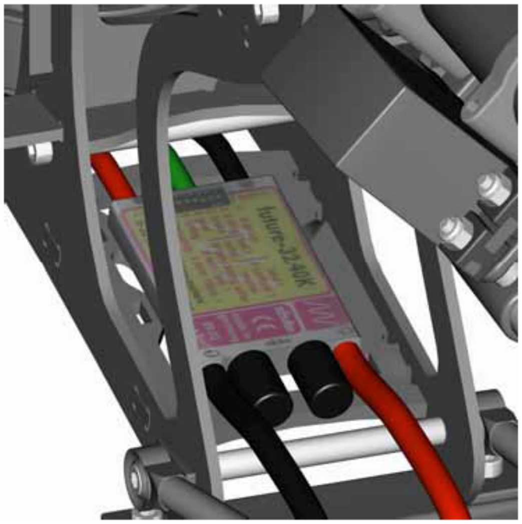


## 5.11 Finished Main Frame with Rotor Head



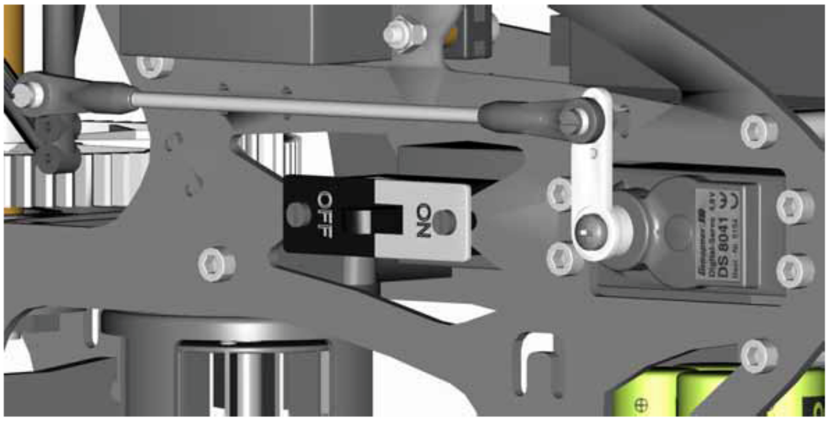
Receiver (attach with double-sided adhesive tape)

Receiver Battery (attach with cable straps)



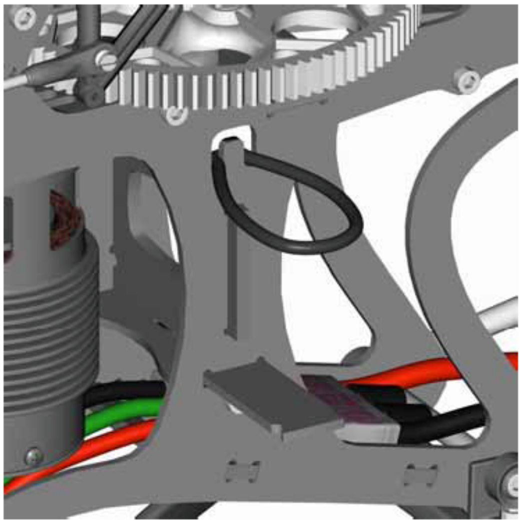
Speed Controller (attach with cable straps)

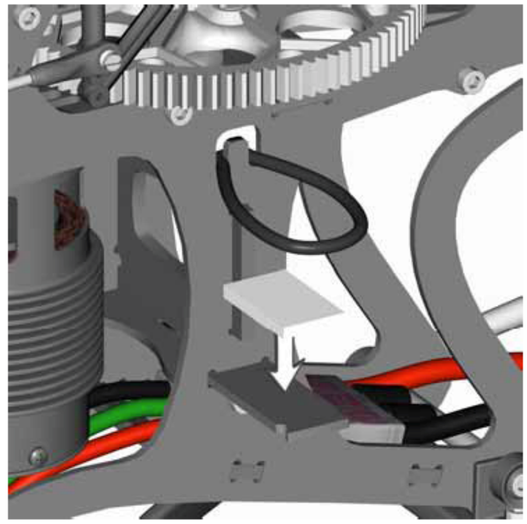
Gyro (attach with double-sided adhesive tape)

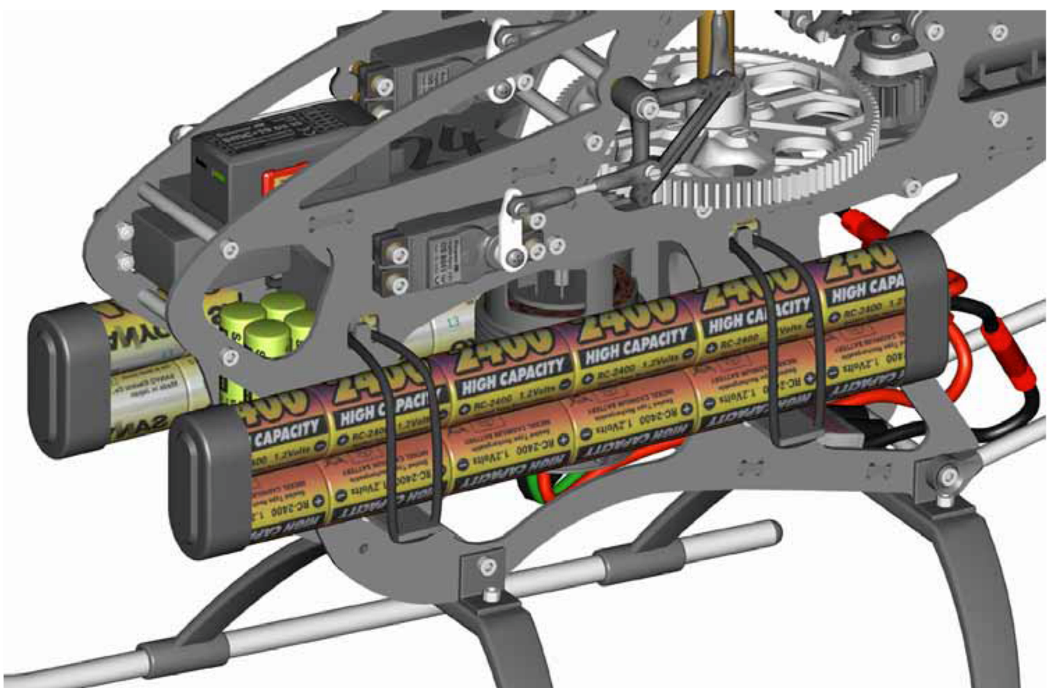




Switch


Battery Fixing Rings (4x #2425)


Foam Layer (#860)



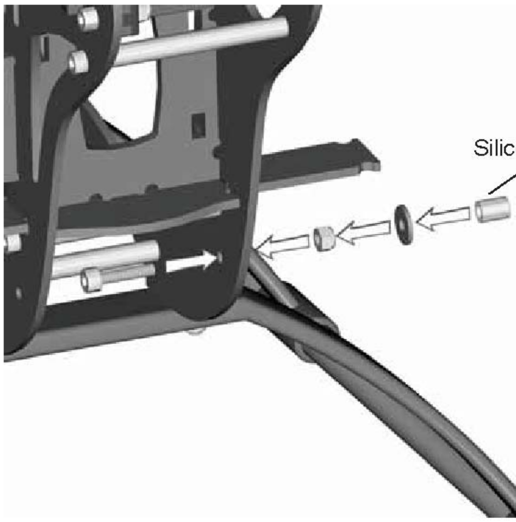
# 7 Canopy

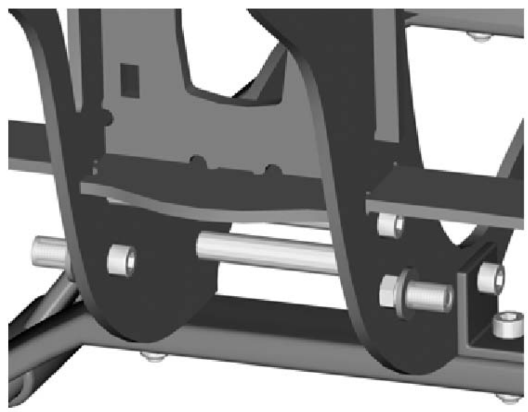
## 7.1 Mounting of Canopy

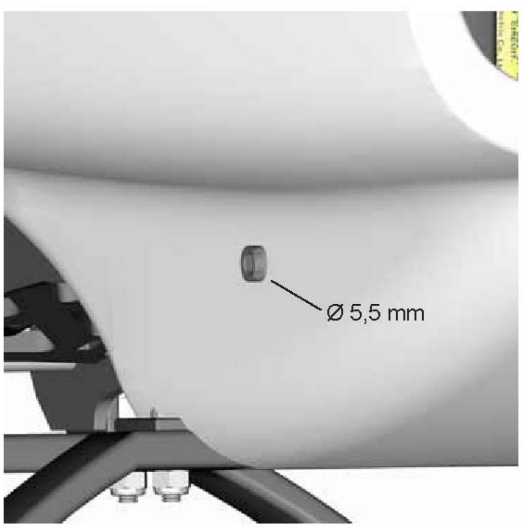
**Bag 1 • Bag 12**

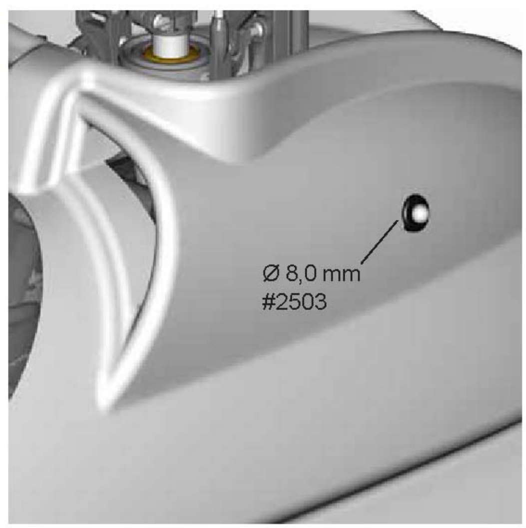
| | | | |
|---|---|---|---|
| 2x | M3x14 | | #1955 |
| 2x | 3x9x1 | | #2011 |
| 2x | Stopp M3 | | #2074 |
| 2x | Ø5mm x 9mm | | #825 |

**Careful:** At first, mount the canopy without using the two rubber rings and without enlarging the two mounting holes. Once you have aligned the canopy in its final position, the two mounting holes can be enlarged to their proper size.

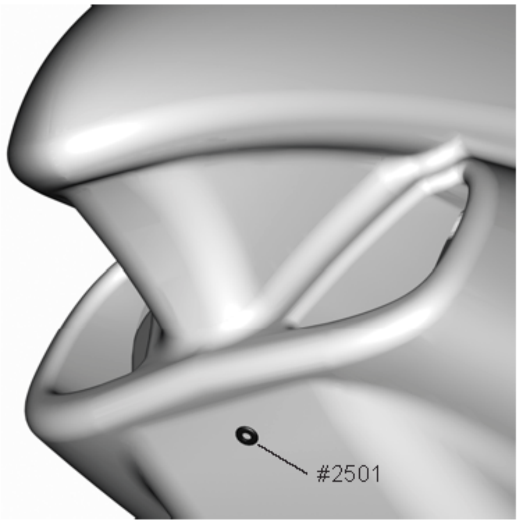




## 7.2 Antenna Placement




**Important:** Place the antenna exactly as shown. This ensures optimal reception in all flight positions.

## 7.3 Decals


Cut out the three horizontal sections of the decal sheet. If you have no experience with applying decals, you may want to use the following trick: Mix a few drops of dish washing detergent with water and spray it onto the canopy's surface. Afterwards apply the decals. You will be able to move them around for a short while until you have found the final position.

BiONiC

# 8 How to avoid interference

**Please read these guidelines carefully in order to fly safely and without electrical interference.**
Flying an electric helicopter means putting several electric components to use. It is essential to avoid that these components create disturbances for one another. The following guidelines tell you how this is achieved.

**1. Placement of cables**

- The wires connecting the motor with the speed controller should be as short as possible. However: Do NOT cut the motor cables (you won't be able to re-solder the connectors properly). But DO shorten the speed controller wires.
- Do not place any wires (servo wire, gyro wire, or antenna wire) in the neighborhood of the speed controller or close to the wires which lead from the speed controller to the motor.
- All wires leading to the receiver should be shortened in such a way that the wires from the servos, gyro and the on/off switch lead to the receiver following the shortest distance possible. Any excess wire will be a source for electrical interference.
- The wires connecting the speed controller with the receiver should be placed at as far away from the motor and from all other electric leads as possible. If you use a Kontronik Tango motor you must use the Kontronik ferrite ring. This is because this motor is operated at a high frequency. If you use any other motor, the use of the ferrite ring is recommended.
- Never place any wires in the direct neighborhood of the tooth belt or the drive pulley.

**2. Gyro**

- Comparison of several gyros has shown that they react differently to the fields generated by the speed controller. Many piezo gyros, in particular the less expensive ones, are quite likely to pick up disturbances. This may result in continuous wiggling or sudden turns of tail. At MIKADO we have found that the new Futaba gyros GY240 and GY401 do not show these problems and that they also work excellent in all other respects.
- Gyros will be sensitive to electric fields when they are placed in the neighborhood of the speed controller, or when the gyro cables are close to the motor or speed controller. It is therefore recommended that you place the gyro on top of the tail boom holder. You may order a special gyro mounting plate from MIKADO (part no. 2486). The GY401, and GY240, due to their smaller size, may also be placed within the RC-frame below the servos.
- As with all cables, place gyro cables away from motor and speed controller.
- Note that if your helicopter appears shaky this is not necessarily due to disturbances. Another source could be that tail pitch slider can't move freely. Check regularly (every 10 flights).

**3. Antenna (very important!)**

- The receiver must be placed in the front of the chassis. The antenna leads through the canopy in a line leading forward (drill small hole through canopy). Get a wire tube and attach it to the landing-bow on one side. Lead the antenna back through the tube. The front part of the tube will stick out in front of the landing bow at least 10 inches. Of the antenna, when it comes out of the tube, only 2 to 3 inches will stick out. In other words, if any part of the antenna is hanging lose, it hangs in front of the nose.
- It is best to attach the atenna tube at the lower antenna holders on the landing bow. Such placement of the antenna will increase the distance between the antenna and other electrical components such as motor, controller and batteries. In this way, reliable performance of the helicopter in all flight positions is ensured.

**4. Receiver**

- Use up-to-date and first-rate dual conversion receivers. Here at MIKADO we use the Graupner JR receiver type DS19 (FM/PPM) or SMC19 DS or SMC20 DS (both SPCM).
- On choice of PCM or PPM: In general, we suggest to use PCM receivers. They have optimal range and they allow for flight without disturbances when all of the above guidelines have been followed. If you are uncertain whether your heli is disturbance-free, it is recommended that you fly PPM first. This allows you to diagnose any potential disturbances.

**5. Battery packs**

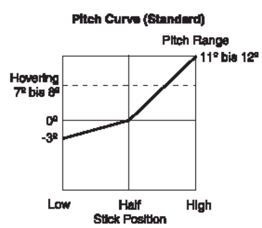
General rule: The more voltage, the more potential for disturbances. Thus, the more cells you fly, the more preventive care should be taken against disturbances. You should use inline battery packs (soldered or connected), because they have both cables in the back (which avoids excess wiring in the front of the helicopter).

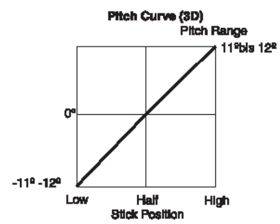
## 9.1 120° Swashplate Mixing (120° CCPM)

The LOGO 24 swashplate is designed to be controlled via electronic CCPM. Thus the corect control inputs of the three swashplate servos are automatically mixed by the R/C transmitter. If you have never programmed 120° CCPM before, please read this introductory text carefully.

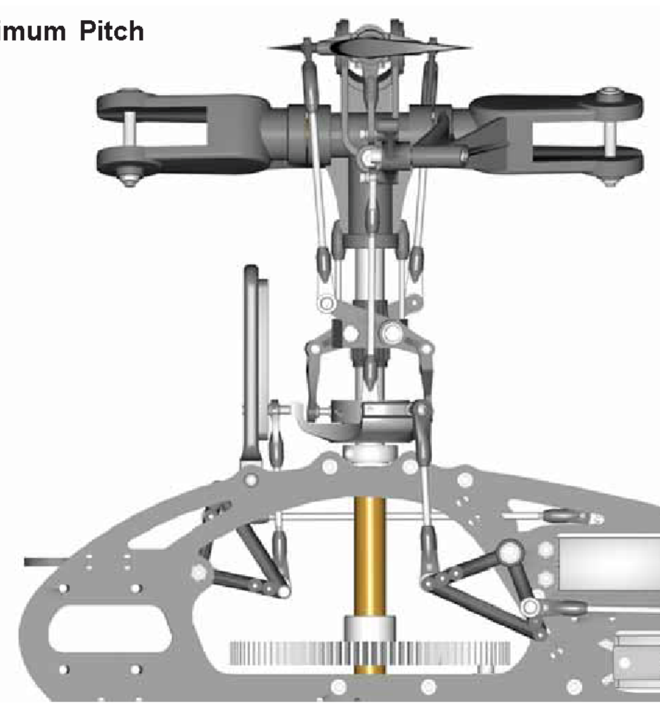
## 9.2 Collective (Pitch)

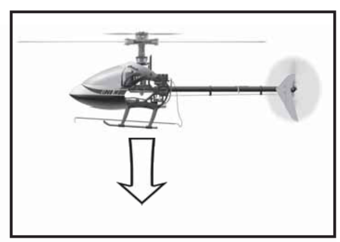
Pitch function is used to control the lift or sink of the helicopter. When pitch input is given, all three swash-plate servos travel together in the same direction and the same amount. As a result the swash-plate moves up or down on an even level.
We strongly recommend to use a pitch gauge for adjusting the pitch values. If you do not wish to use the full pitch range (-12° to +12°), you may set the pitch values for minimum and maximum pitch separately in the R/C transmitter. If you are new to the hobby, we recommend to set minimum pitch at 3°.



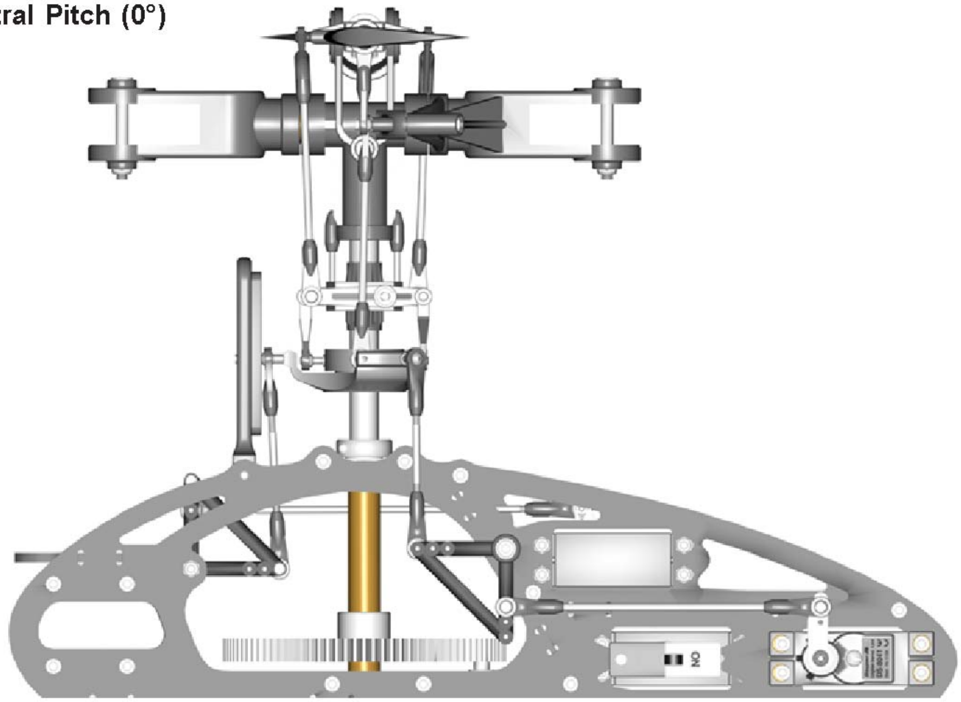




### Minimum Pitch

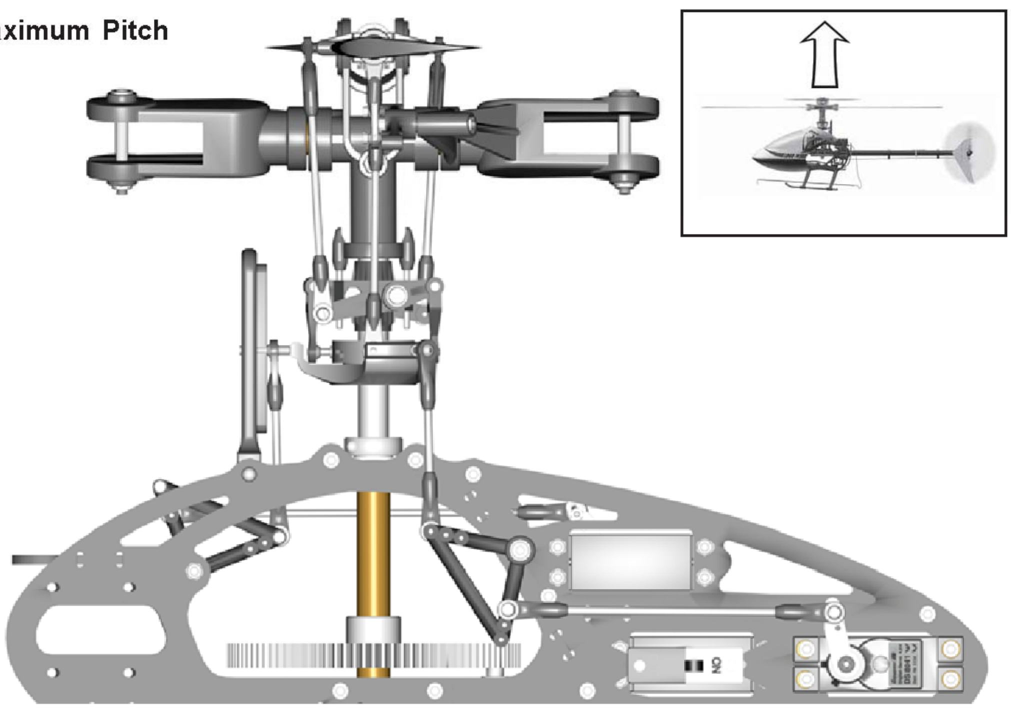




**Neutral Pitch (0°)**

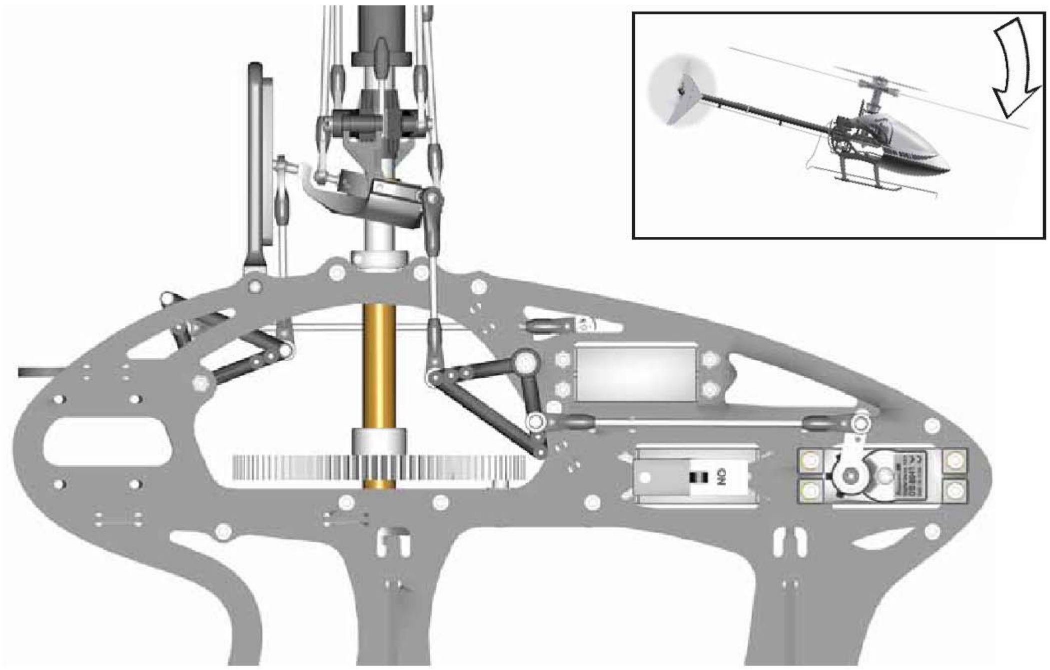


**Maximum Pitch**



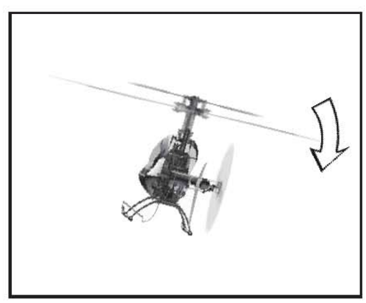
## 9.3 Elevator (Tilt)

For tilting the helicopter, use the elevator function. For tilting forward, the two aileron servos move downward and the backward elevator servo moves upward. The elevator servo moves twice as much as the two aileron servos.



## 9.4 Aileron (Roll)

Aileron (roll) is used to control the helicopter's movements around its longitudinal axis. When aileron (roll) input is given, the two roll servos (in the front of the swashplate) travel in opposite directions. As a result the swash-plate tilts to the right or to the left.



## 9.5 Programming 120° CCPM

As the programming procedure varies with different types of R/C systems, it is necessary for you to refer to the instruction manual of your R/C system. Here are only a few general guidelines which apply to most systems.

### Servo Centering with Sub-Trim Function

As indicated in the above sections on mounting the servos, it is important that the servo arms are exactly centered. You should use the servo sub-trim function of your R/C system for this purpose.

### Activating 120° CCPM

Likely, the 120° CCPM function is initially disabled in your R/C transmitter software and needs to be separately activated. Please refer to your R/C system manual, where you will also find information on which channels should be used for the elevator servo and the two roll servos. It is important that you stick with the requirements stated in the manual. Otherwise the 120° CCPM will not function properly.

Your R/C may support various different CCPM mixings. For Logo 24 choose the 120° mixing with two roll servos in the front and one elevator servo in the back.

Use the relevant menus for setting the mixing proportions for roll, elevator and pitch functions. Begin by setting the mix values to 50% each. Higher mix values give higher servo travel for that function This can have the unwanted result that the swashplate reaches its limits and causes damage to the servos or rods or to the swash-plate itself.

If necessary, you may use the CCPM menu to reverse the direction of the function. This is necessary, for example, if the swash-plate tilts to the wrong side or the pitch function is inverted. The menu for reversing servo functions can be used for reversing the movements of individual servo arms, but not for reversing the entire control function and of all the involved servos.

### Aileron and Elevator Travel

The travel range of the aileron and elevator servos are limited by the swashplate's mechanical limits. Please take care that the swashplate does not hit the maximum of its travel. This can have the unwanted result that the swashplte reachies its mechanical limits and causes damage to the servos or rods or to the swashplate itself. e Gestänge und die Taumelscheibe.

If you desire more agility for your helicopter, use lighter flybar paddles.

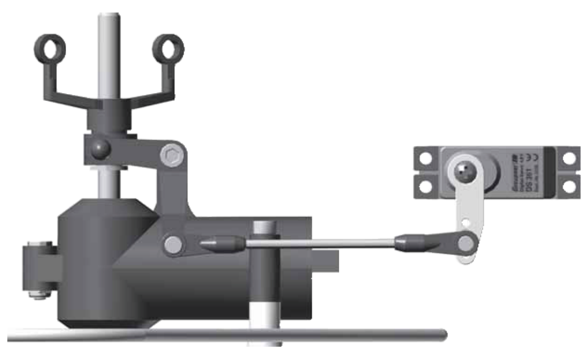
## 9.6 Tail Rotor Settings

When the servo arm of the tail rotor servo is in the center, the tail rotor lever and the servo arm should be perpendicular with respect to each other. The tail rotor pitch lever should never reach its mechanical limits.

In case the servo travel is too large, you have the following options for correcting this:
1. Move the ball end of the tail rotor servo closer to the center of the servo arm.
2. Reduce the servo travel in your R/C system using ATV.
3. Reduce the servo travel in your gyro (not all gyros have this option).

In case the servo travel is too small, you have the following options for correcting this:
1. Move the ball end of the tail rotor servo further away from the center of the servo arm.
2. Increase the servo travel in your R/C system using ATV.
3. Increase the servo travel in your gyro (not all gyros have this option).

Ensure that the tail rotor servo turns in the correct direction. If necessary, reverse the direction of the tail rotor servo function in your R/C system.



Adjust the tail rotor linkage in length such that the tail rotor servo arm and the tail rotor lever are at 90 with respect to each other.
All parts serving the tail rotor movements must move smoothly. When there is too much resistance, the tail rotor will not react to subtle input and the gyro's maximum sensitivity cannot be fully exploited.

## 9.7 Revo-Mix/Gyro

It is necessary to compensate for the torque created by the motor during flight (but not during autorotation). This compensation is done by adjusting the tail rotor pitch. There are two options for achieving this:

1. Using normal gyro mode
Please refer to your R/C system manual for activating the revolution mixing function and for setting all parameters correctly. Final settings should be trimmed during test flights.

2. Using a gyro in Heading-Hold mode
The Heading-Hold gyro mode compensates automatically the deviation caused by the motor torque. Therefore, if Heading-Hold mode is used, revo-mix should not be programmed additionally.

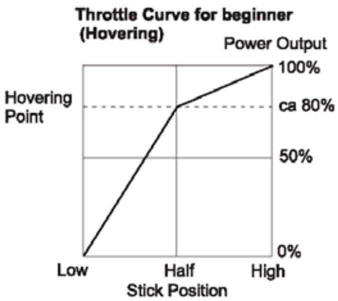
Important: Check to ensure that the tail rotor assembly moves smoothly and without play. Otherwise the gyro and servo will not compensate the torque properly.

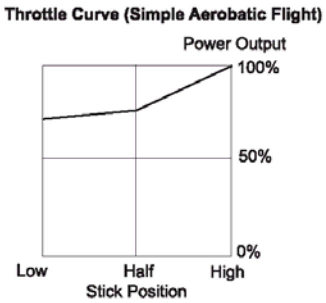
## Rotor Head RPM control

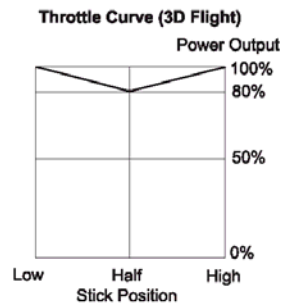
LOGO 24 is designed to be flown with constant rotor head speed. Irrespective of flight attitude (ascending, descending, hovering), rotor speed should be kept roughly constant. There are two different methods for obtaining constant rotor speed:

**Rotor speed control with speed controller**
All speed controllers can be used in this mode. With speed controller it is necessary to program a throttle curve (see manual). Programming of throttle curve requires that you associate a given throttle value with a particular pitch value. In this way, the rotor speed is held almost constant with all pitch values.

Throttle curve programming depends on the type and quality of the R/C system. Simpler, inexpensive R/C systems designed for model helicopters usually have a 3-point throttle curve. High-end R/C systems typically have throttle curves with more configurable points (up to 9). Fine tuning of throttle curves will be necessary during test flights.




Note that an incorrectly programmed throttle curve reduces performance and can lead to overheating of the motor and the speed controller.

**Rotor speed control with governor (RPM regulation mode)**
A speed controller with governor function keeps the rotor head speed constant, independent of flight attitude (ascending, descending, hovering). It is not necessary to program a throttle curve. The head speed is simply controlled on the radio transmitter using a switch or lever.
Important:
1) Governor mode must be activated in the speed controller first (see manual of the speed controller)
2) In governor mode, the servo wire of the speed controller must not be connected to the throttle channel. Use a free channel in your radio to connect the servo wire.

# 10 Rotor Blades


**10.1 Balancing of Rotor Blades (Center of Gravity)**

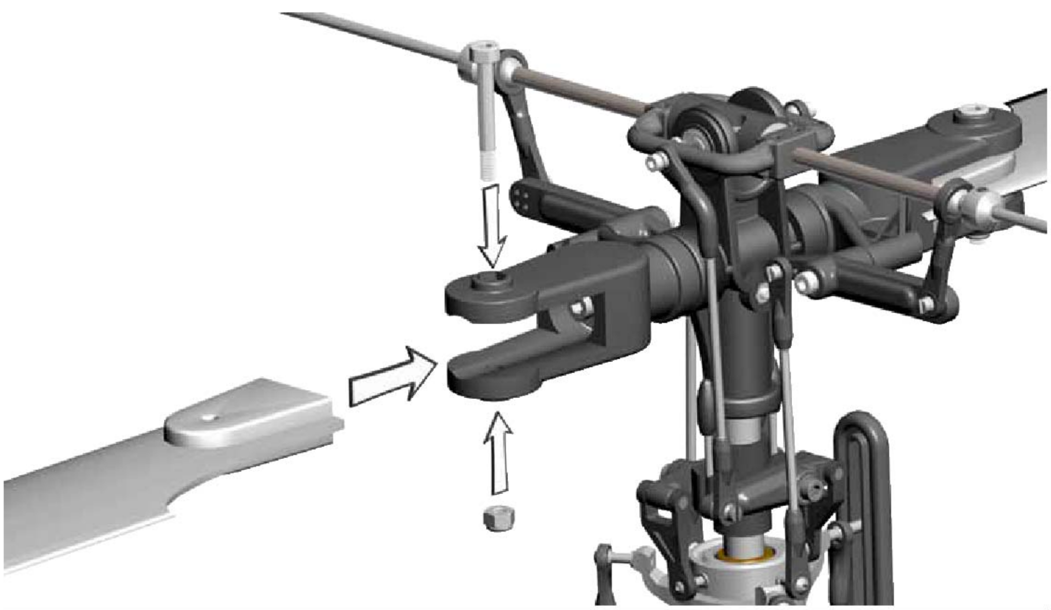
Place each rotor blade over an edge as shown in picture (1). Adjust the blades so that they are in equilibrium. If the center of gravity is not in the same place in each blade, this needs to be corrected using tape. Apply as much tape as necessary until both blades show their center of gravity in the same place.

**10.2 Static balancing**

Screw the rotor blades together as shown in picture (2). The rotor blades are properly balanced when they are suspended exactly horizontally. If one of the rotorblades is not exactly horizontal, the blades are not in equilibrium.


This is corrected by applying tape to lighter blade.

When mounting the rotor blades to the blade holders, note the proper direction (clockwise rotation). Tighten the cap screws holding the rotor blades, so that the blades cannot move easily in the blade holders.



# 11 Final Pre-Flight Check

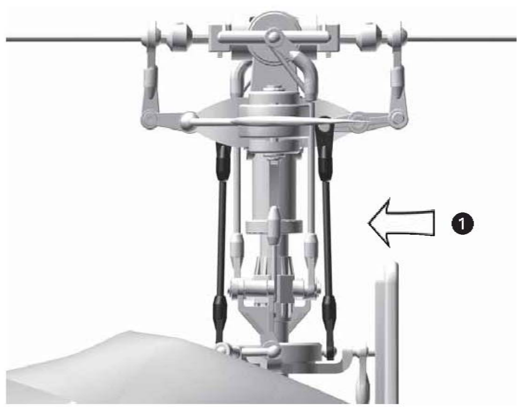
## 11.1 Direction of Main and Tail Rotation

Prior to the first flight double-check the direction of rotation of the main rotor head and the tail rotor. For this, turn the main gear clock-wise.

## 11.2 Blade Tracking Adjustment

Incorrect

OK



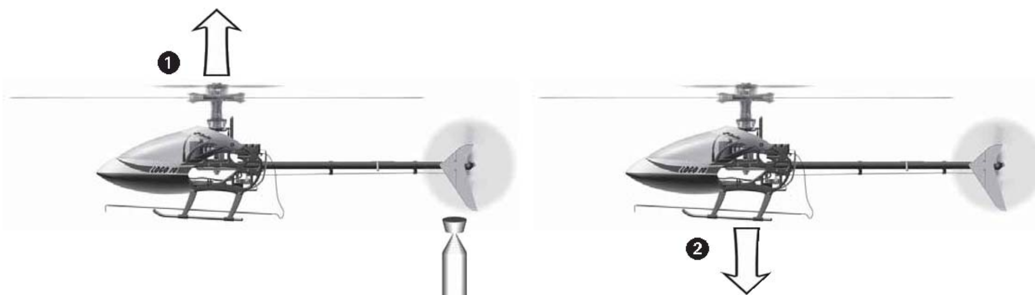

Prior to the first flight the tracking of the rotor blades needs to be adjusted. If the tracking is not adjusted properly, this can cause vibrations and lead to instability of the helicopter.

Apply colored tape to the tip of one of the rotor blades. Apply tape of a different color to the tip of the other rotor blade. When you are ready for your first flight, increase the rotor speed to just before lift-off. From a safe distance, check the rotor disk at eye-level. Very likely, one rotor blade will move below the other.

Make a note of the color of the low-moving blade. Then turn off the motor and wait until the rotor head has come to a halt. Lengthen the linkage (1) of the rotor blade which was moving low by unscrewing the ball links somewhat. Repeat the checking procedure until both rotor blades move on the same level.

# 12 Control Movements

## 12.1 Pitch/Throttle

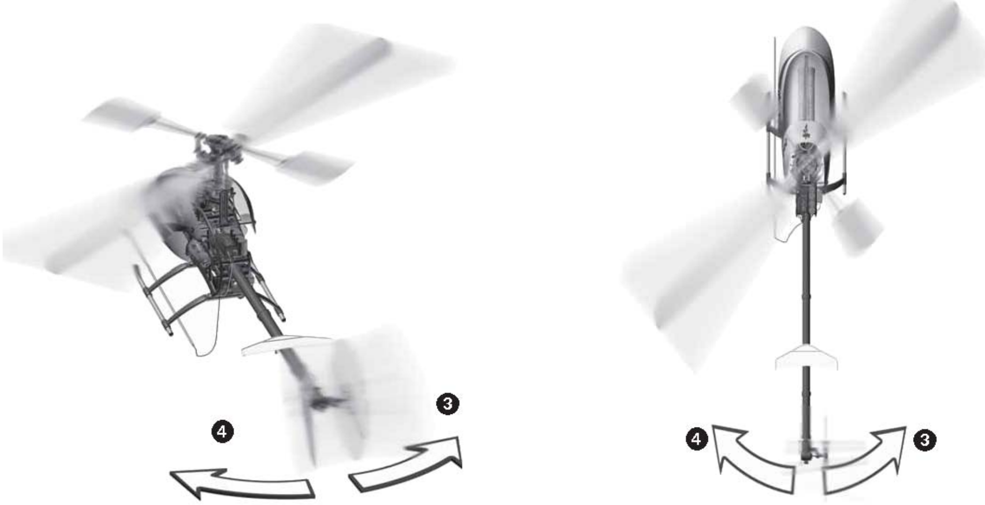




You may want to program a different stick mode than the one shown. Please check which stick mode is used by other local pilots. Use the same one, so fellow pilots can assist you on the field.

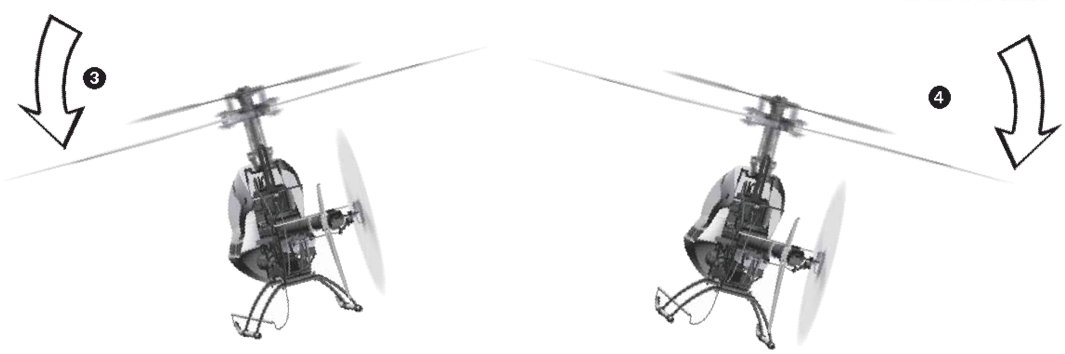
**Important:** Flying a model helicopter requires many hours of training. During your first attempts, while familiarizing yourself with the different control movements, keep the helicopter low above the ground (just a few centimeters/a couple of inches.)

## 12.2 Rudder



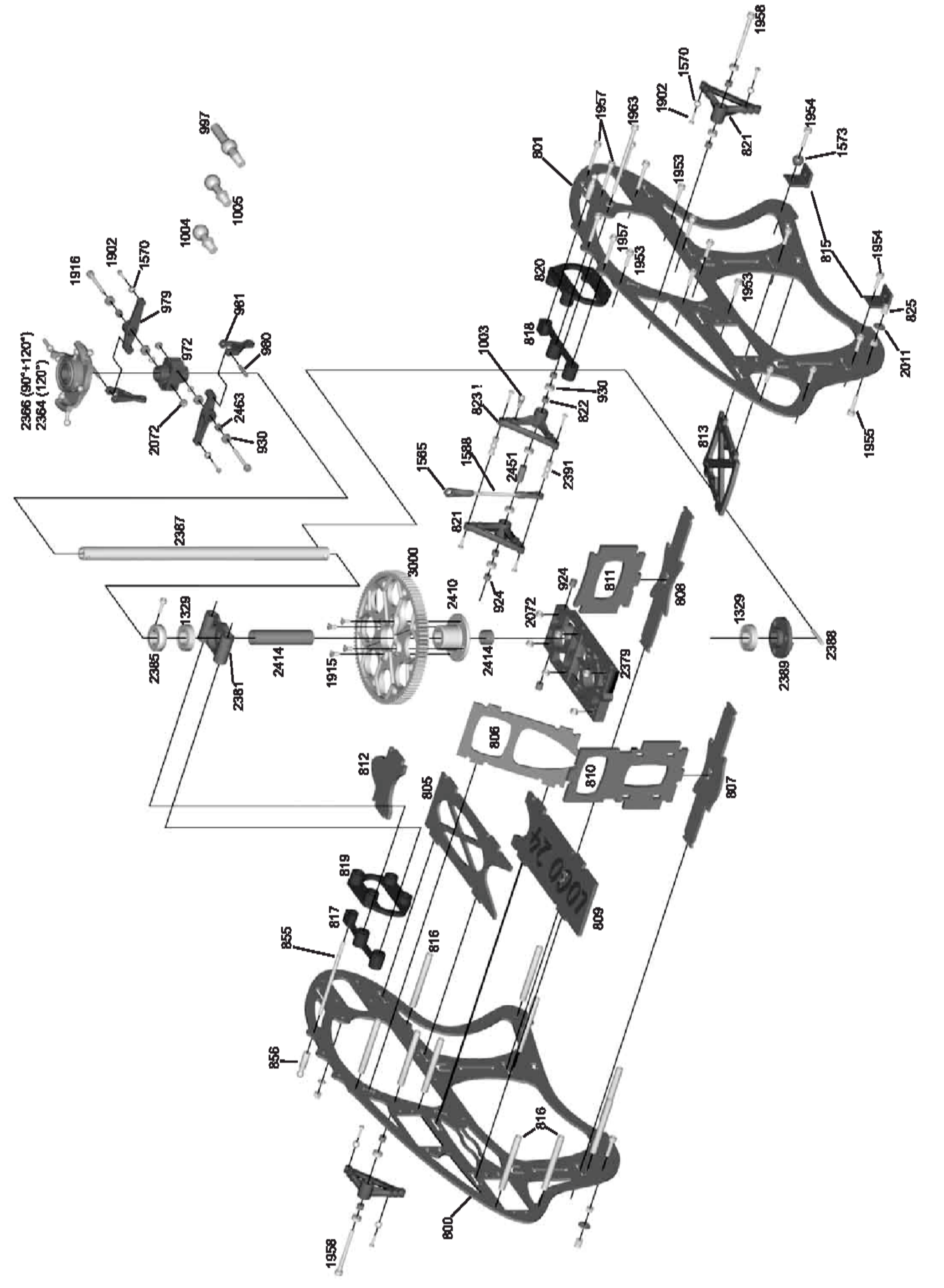
## 12.3 Elevator


## 12.4 Aileron

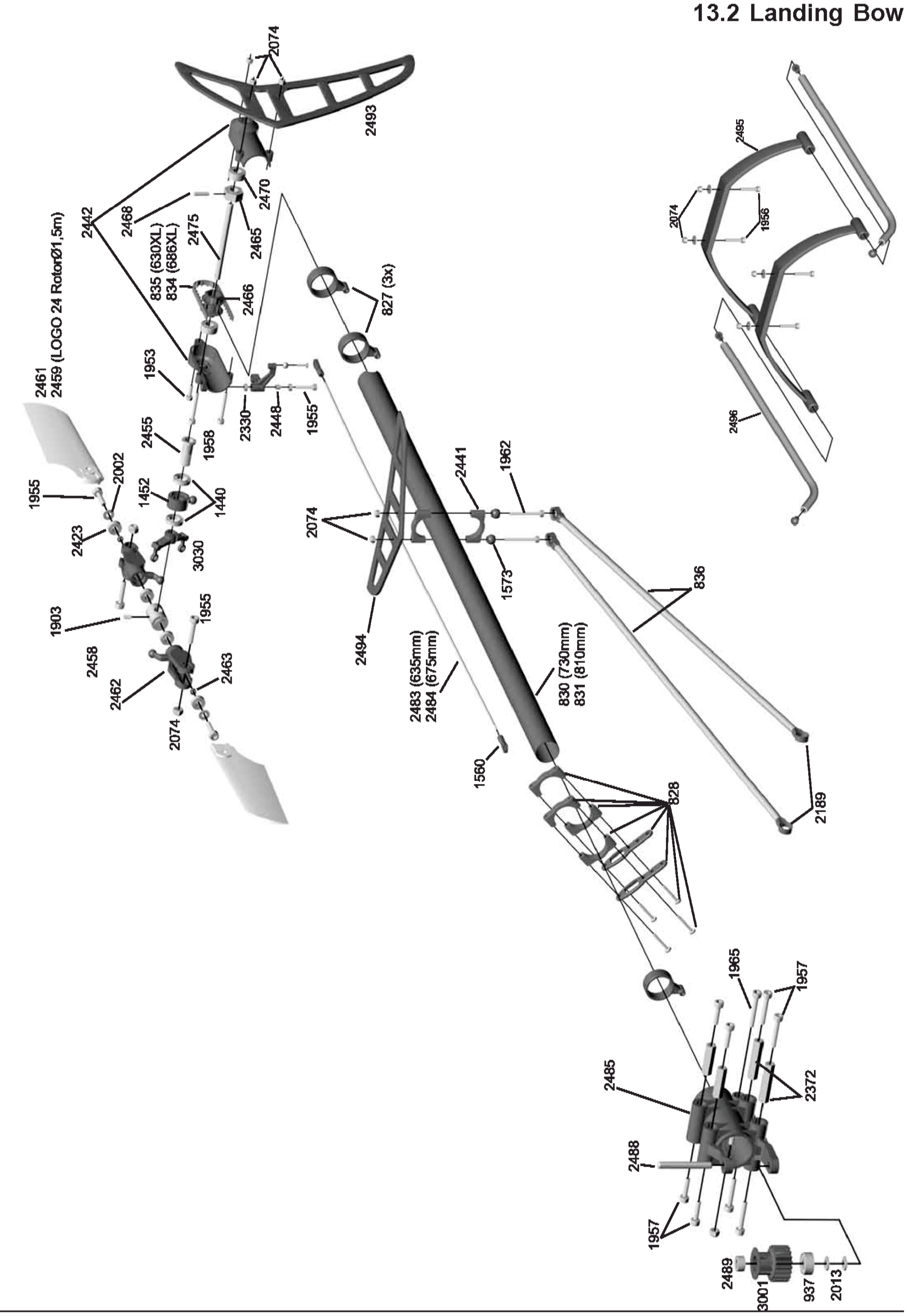


# 13 Overview

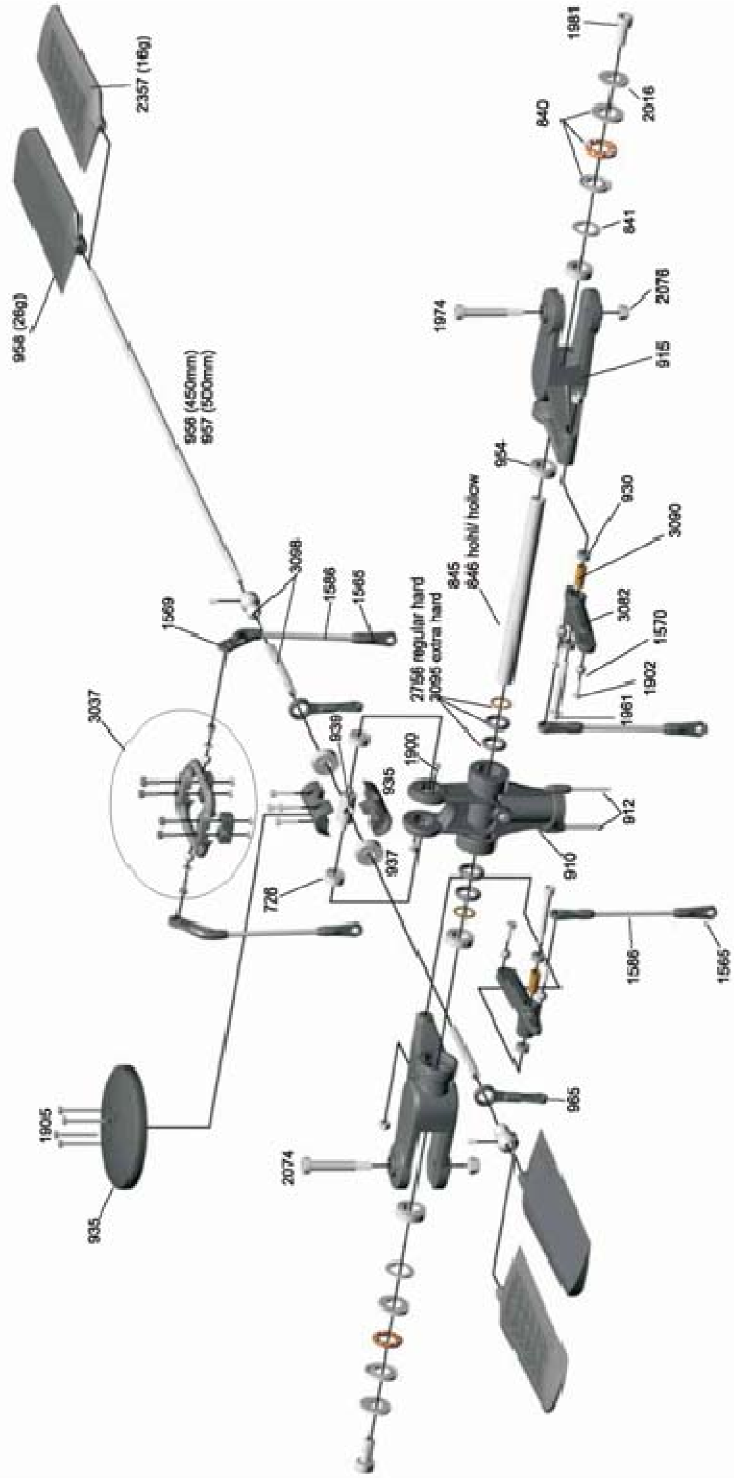
## 13.1 Chassis



## 13.2 Landing Bow



## 13.3 Rotor Head



# 14 Tuning/Accessories

Tail rotor hub with
thrustbearings #3052

Carbon tail rotor upgrade
set #3062

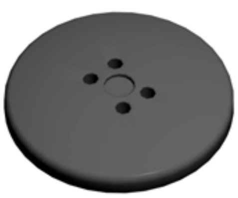
carbon servo
holder for tailboom #828

Alu washout unit #973

light paddles #2357

Alu motorplate #3061

Rotor disk #932




Mikado
Modellhubschrauber
www.mikado-heli.de
LOGO 24
BIONIC
Construction & Rendering: Mehran Mahinpour Tirooni – Layout & Realisation: ©DT-Berlin

# APPENDIX G. UNAV_DATASHEET

Crossbow

# MNAV

NAVIGATION & SERVO CONTROL BOARD

- Miniature, Low Cost Robotic Vehicle Sensor Suite
- Onboard R/C Servo Controller
- Standard 51-Pin Connector for Optional Stargate Auto-Pilot Interface
- Pre-installed with Open Source Inertial Firmware
- Sensor Calibration and Servo Control via MICRO-VIEW User Interface

## Applications

- Radio Control Fixed and Rotary Wing Aircraft
- Robotics Navigation and Control
- Indoor UAV Lab

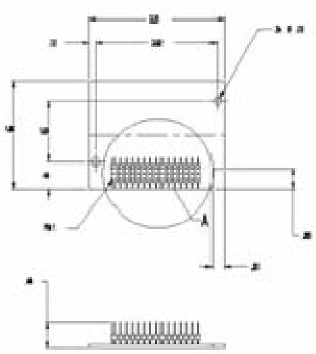
## MNAV100CA

The MNAV100CA is a calibrated digital sensor and servo control system designed for use in Radio Control (R/C) vehicles. The onboard sensor package includes accelerometers, angular rate sensors, and magnetometers for use in inner loop control applications as well as static pressure (altitude) and dynamic pressure (airspeed) sensors for use in airborne robotics. A GPS sensor is also included for both path planning and navigation.

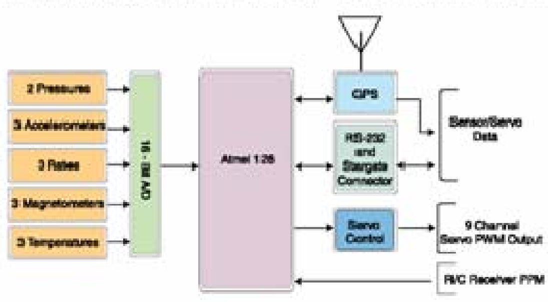
The MNAV100CA's comprehensive onboard servo control solution includes both R/C servo control hardware and an R/C receiver Pulse Position Modulation (PPM) interface. R/C servo hardware provides users with software-based control of up to nine separate servos while the PPM interface enables software interpretation of R/C receiver commands thereby offering users both automated software control as well as manual "takeover" capability.

Output data are provided in a digital (RS-232) format. Each MNAV100CA system comes with a GPS antenna, interface cables and User's Manual. Crossbow's MICRO-VIEW software is also included to assist users with sensor calibration, servo control, data collection and overall system development.

When connected to Crossbow's Stargate Processor Board (SPB400), via the standard 51-pin connector, the MNAV100CA combines with the SPB400 to form a sophisticated open-source robotics platform. This comprehensive robotics solution offers users a flexible development platform



Package Dimensions




MNAV Block Diagram

Document Part Number: 6020-0083-02 Rev B

Phone: 408.965.3300 • Fax: 408.324.4840 • E-mail: info@xbow.com • Web: www.xbow.com

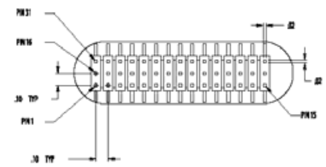
Crossbow

| Specifications | MNAV100CA | Remarks |
|---|---|---|
| **Performance** | | |
| Update Rate (Hz) | 2-100 | User Programmable |
| Angular Rate Range | ± 150 | |
| Acceleration Range X/Y/Z (g) | ± 2 | |
| Inertial Sensor Bandwidth (Hz) | > 25 | -3 dB point |
| Magnetometer Range (G) | ± 0.75 | |
| Altitude Range (m,MSL) | 0-5000 | |
| Airspeed Range (m/s) | 0-80 | |
| GPS Accuracy (m) | 3 | CEP |
| **Environment** | | |
| Operating Temperature (°C) | -5 to +45 | |
| **Electrical** | | |
| Input Voltage (VDC) | 3.7 to 16 | |
| Power Consumption (W) | < 0.8 | at 5 VDC |
| Digital Output Format | RS-232 | |
| **Physical** | | |
| Size (in) | 2.25 x 1.80 x 0.44 | |
| (cm) | 5.70 x 4.50 x 1.10 | |
| Weight (g) | 33 | |
| Connector | 15X3 Array of 0.1 inch square pins | |

Notes: Specifications subject to change without notice

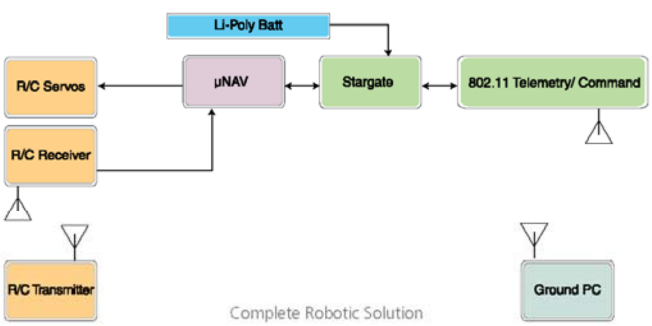
for state estimation, WiFi telemetry command uplink/downlink and closed-loop navigation and control. Payload sensors (e.g. USB image sensor) can also be connected and processed by the Stargate to support intelligent robotics applications.

MNAV integrated with Complete Robotics Hardware



| Pin | Function |
|---|---|
| 1-15,31 | Ground |
| 16,32 | Input Power |
| 17,20-30 | Servo Power |
| 18 | RS-232 Receive Port 0 |
| 33 | RS-232 Transmit Port 0 |
| 19 | RS-232 Receive Port 1 (GPS) |
| 34 | RS-232 Transmit Port 1 (GPS) |
| 35 | PPM Input |
| 36 | High Speed Servo PWM |
| 37 | Servo 8 PWM |
| 38 | Servo 7 PWM |
| 39 | Servo 6 PWM |
| 40 | Servo 5 PWM |
| 41 | Servo 4 PWM |
| 42 | Servo 3 PWM |
| 43 | Servo 2 PWM |
| 44 | Servo 1 PWM |
| 45 | Servo 0 PWM |

MNAV100 Pin Diagram




Complete Robotic Solution

## Ordering Information

| Model | Description | Gyro (°/sec) | Accel (g) |
|---|---|---|---|
| MNAV100CA | Navigation and Servo Control Board | ± 150 | ± 2 |

CALL FACTORY FOR OTHER CONFIGURATIONS

Document Part Number: 6020-0083-02 Rev B

# APPENDIX H. UAV SURROGATE WORK LOG

| Step | Discription | Time (min) | Technical Assist. Needed | Special Tools Needed | Tech Assist Time | Special Tool Time |
|---|---|---|---|---|---|---|
| 1 | Main Frame | | | | | |
| 1.1 | Servo Installation | 38 | No | No | 0 | 0 |
| 1.2 | Motor Plate | 2 | No | No | 0 | 0 |
| 1.3 | Battery Holder and R/C Plate | 45 | No | No | 0 | 0 |
| 1.4 | Controller Plate and Gyro Plate | 90 | No | No | 0 | 0 |
| 1.5 | Chassis Assembly | 42 | No | No | 0 | 0 |
| 1.6 | Final Chassis Assembly | 63 | No | No | 0 | 0 |
| 1.7 | Landing Gear | 56 | No | No | 0 | 0 |
| 1.8 | Bearing Case | 20 | No | No | 0 | 0 |
| 1.9 | Main Gear | 65 | No | No | 0 | 0 |
| 1.10 | Main Rotor Shaft | 38 | No | No | 0 | 0 |
| 1.11 | Elevator Lever | 10 | No | No | 0 | 0 |
| 1.12 | Aileron Lever | 8 | No | No | 0 | 0 |
| 1.13 | Linkages | 72 | No | No | 0 | 0 |
| 1.14 | Servo Arms | 16 | No | Yes | 0 | 16 |
| 1.15 | Elevator Linkage | 65 | No | Yes | 0 | 65 |
| 1.16 | Aileron Linkage | 64 | No | Yes | 0 | 64 |
| 1.17 | Swashplate | 63 | No | No | 0 | 0 |
| 1.18 | Washout | 63 | No | No | 0 | 0 |
| 1.19 | Swashplate Guide | 71 | No | No | 0 | 0 |
| 1.20 | Installation of Washout | 7 | No | Yes | 0 | 7 |
| 1.21 | Finished Main Frame | 0 | No | No | 0 | 0 |
| | | 898 | | | 0 | 152 |
| 2 | Motor Installation | | | | | |
| 2.1 | Motor Installation and Pinion | 7 | Yes | No | 7 | 0 |
| 2.2 | Adjusting Gear Backlash | 53 | Yes | No | 53 | 0 |
| 2.3 | Tail Rotor Shaft | 77 | No | No | 0 | 0 |
| 2.4 | Vertical Fin | 97 | No | No | 0 | 0 |
| 2.5 | Tail Pitch Slider | 39 | No | No | 0 | 0 |
| | | 273 | | | 60 | 0 |
| 3 | Tail Rotor | | | | | |
| 3.1 | Tail Rotor Shaft | 84 | No | No | 0 | 0 |
| 3.2 | Vertical Fin | 31 | No | No | 0 | 0 |
| 3.3 | Tail Pitch Slider | 39 | No | No | 0 | 0 |
| 3.5 | Tail Rotor Hub | 77 | No | No | 0 | 0 |
| | | 231 | | | 0 | 0 |
| 4 | Tail | | | | | |
| 4.1 | Tail Boom Assembly | 50 | No | No | 0 | 0 |
| 4.2 | Tail Boom Holder | 38 | No | No | 0 | 0 |
| 4.3 | Tail Drive Pulley | 24 | No | No | 0 | 0 |
| 4.4 | Tail Servo Holder | 14 | No | No | 0 | 0 |
| 4.5 | Horizontal Fin | 82 | No | No | 0 | 0 |
| 4.6 | Tail Control Rods | 84 | Yes | Yes | 84 | 84 |
| 4.7 | Tail Assembly | 9 | No | No | 0 | 0 |
| 4.8 | Tail Boom Brace | 20 | No | No | 0 | 0 |
| 4.9 | Tail Rotor Blades | 99 | No | No | 0 | 0 |
| 4.10 | Main Frame With Tail Boom | 0 | No | No | 0 | 0 |
| | | 420 | | | 84 | 84 |

| Step | Discription | | Technical Assist. Needed | Special Tools Needed | Tech Assist Time | Special Tool Time |
|---|---|---|---|---|---|---|
| 5 | Main Rotor Head | | | | | |
| 5.1 | Blade Grips | 47 | No | No | 0 | 0 |
| 5.2 | Mixing Arms | 36 | No | No | 0 | 0 |
| 5.3 | Yoke, Spindle, Shaft | 47 | No | No | 0 | 0 |
| 5.4 | Seesaw | 47 | No | No | 0 | 0 |
| 5.5 | Flybar Control Bridge | 21 | No | No | 0 | 0 |
| 5.6 | Flybar | 47 | Yes | Yes | 47 | 47 |
| 5.7 | Flybar Paddles | 30 | No | No | 0 | 0 |
| 5.8 | Final Assembly | 95 | No | No | 0 | 0 |
| 5.9 | Rotor Head Linkage | 77 | No | No | 0 | 0 |
| 5.10 | Rotor Disk | 72 | No | No | 0 | 0 |
| 5.11 | Finished Main Frame with Rotor Head | 0 | No | No | 0 | 0 |
| | | 519 | | | 47 | 47 |
| 6 | Avionics,Wireing and Power Installation | | | | | |
| 6.1 | Receiver Installation | 95 | Yes | No | 95 | 0 |
| 6.2 | Heading Gyro Installation | 34 | Yes | No | 34 | 0 |
| 6.3 | Servo Control Lead Installation | 76 | Yes | No | 76 | 0 |
| 6.4 | Receiver Battery Installation | 54 | No | No | 0 | 0 |
| 6.5 | Motor Controller Installation | 98 | Yes | Yes | 98 | 98 |
| 6.6 | Main Switch Installation | 14 | No | No | 0 | 0 |
| 6.7 | Main Battery Installation | 38 | No | Yes | 0 | 38 |
| 6.8 | Antenna Placement | 63 | No | No | 0 | 0 |
| 6.9 | Canopy Installation | 27 | No | No | 0 | 0 |
| | | 499 | | | 303 | 136 |
| 7 | RC Programming | | | | | |
| 7.1 | 120o Swashplate Mixing (120o CCPM) | 18 | Yes | Yes | 18 | 18 |
| 7.2 | Collective (Pitch) | 13 | Yes | Yes | 13 | 13 |
| 7.3 | Elevator (Tilt) | 61 | Yes | Yes | 61 | 61 |
| 7.4 | Aileron (Roll) | 95 | Yes | Yes | 95 | 95 |
| 7.5 | Programming 120o CCPM | 56 | Yes | Yes | 56 | 56 |
| | | 243 | | | 243 | 243 |
| 8 | Axis Trims | | | | | |
| 8.1 | Servo Centering with Sub-Trim Function | 18 | Yes | No | 18 | 0 |
| 8.2 | Activating 120o CCPM | 97 | Yes | No | 97 | 0 |
| 8.3 | Aileron and Elevator Travel | 46 | Yes | No | 46 | 0 |
| 8.4 | Tail Rotor Settings | 23 | Yes | No | 23 | 0 |
| 8.5 | Revo-Mix/Gyro | 65 | Yes | No | 65 | 0 |
| 8.6 | Rotor Head RPM Control | 29 | Yes | No | 29 | 0 |
| 8.7 | Balancing of Rotor Blades (Center of Gra\ | 91 | Yes | No | 91 | 0 |
| 8.8 | Static Balancing | 33 | No | No | 0 | 0 |
| | | 402 | | | 369 | 0 |
| 9 | Flight Testing | | | | | |
| 9.1 | Direction of Main and Tail Rotation | 2 | No | Yes | 0 | 2 |
| 9.2 | Blade Tacking Adjustment | 26 | Yes | Yes | 26 | 26 |
| 9.3 | Pitch/Throttle | 57 | Yes | Yes | 57 | 57 |
| 9.4 | Rudder | 94 | Yes | Yes | 94 | 94 |
| 9.5 | Elevator | 48 | Yes | Yes | 48 | 48 |
| 9.6 | Aileron | 35 | Yes | Yes | 35 | 35 |
| | | 262 | | | 260 | 262 |
| | Total | 3747 | | | 1366 | 924 |

# LIST OF REFERENCES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